TravTek Evaluation
Safety Study

Publication No. FHWA-RD-95-188

February 1996

U.S. Department of Transportation
Federal Highway Administration

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia

FOREWORD

This report is one of eight reports produced as part of the evaluation of the TravTek operational field test, conducted in Orlando, Florida, during 1992-1993. TravTek, short for Travel Technology, was an advanced driver information and traffic management system that provided a combination of traveler information services and route navigation and guidance support to the driver. Twelve individual but related studies were conducted during the evaluation. Evaluation goals and objectives were represented by the following basic questions: (1) Did the TravTek system work? (2) Did drivers save time and avoid congestion? (3) Will drivers use the system? (4) How effective was voice guidance compared to moving map and turn-by-turn displays? (5) Was TravTek safe? (6) Could TravTek benefit travelers who do not have the TravTek system? (7) Will people be willing to pay for TravTek features?

Evaluation data were obtained from more than 4,000 volunteer drivers during the operation of 100 specially equipped automobiles for a 1-year period. Results of the evaluation demonstrated and validated the concept of in-vehicle navigation and the provision of traveler information services to the driver. The test also provided valuable results concerning the drivers' interaction with and use of the in-vehicle displays. This project has made many important contributions supporting the goals and objectives of the Intelligent Transportation Systems Program.

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Acting Director, Office of Safety and Traffic Operations Research and Development

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-95-188		

4. Title and Subtitle	5. Report Date
TRAVTEK EVALUATION SAFETY STUDY	February 1996
	6. Performing Organization Code
7. Author(s) William A. Perez, Michel VanAerde, Hesham Rakha, and Mark Robinson	8. Performing Organization Report No.
9. Performing Organization Name and Address Science Applications International Corporation 1710 Goodridge Drive McLean, Virginia 22102	10. Work Unit No. (TRAIS) 3B7A 11. Contract or Grant No. DTFH61-91-C-00106
12. Sponsoring Agency Name and Address Office of Safety and Traffic Operations R&D Federal Highway Administration 6300 Georgetown Pike, McLean, Virginia 22101-2296	13. Type of Report and Period Covered Final Report, Nov. 1991 - June 1994 14. Sponsoring Agency Code

15. Supplementary Notes

Contracting Officer's Technical Representative: Frank Mammano, HSR-12

16. Abstract

One of the major evaluation goals of the TravTek operational test was to assess the safety impact of the TravTek system as implemented in Orlando, Florida during the 1 -year deployment phase. Also, the results of the TravTek operational test, with respect to safety, were to be used to estimate the potential safety impact of a TravTek-like system under levels of high market penetration.

The TravTek study entailed the collection of multiple safety-related measures across five different empirical studies. The empirical studies included two field studies with renters and local drivers that used the vehicles under normal driving conditions. In addition, three experimental field studies were conducted that included a camera car vehicle which was used to collect detailed driver performance and behavior data. Converging evidence from these empirical studies showed that the TravTek in-vehicle system did not degrade driver safety. The simplified Turn-by-Turn display was shown to lead to safest performance. Also, the Voice display of route guidance information was shown to enhance the safety of the complex Route Map display. As part of conducting a trade-off analyses between safety benefits and safety costs, safety related data from the five empirical studies were fused and used as input to the INTEGRATION model. The INTEGRATION model was used to project the potential safety benefits and costs associated with a TravTek system under high levels of market penetration.

17. Key Words	18. Distribution Statement
TravTek, Safety, Modeling, Navigation	No Restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	124	

Form DOT F 1700.7 (8-72)
(PF V2.1, 12/13/93)

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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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OVERVIEW

The TravTek Safety Study presents a comprehensive analysis of the TravTek Operational Test from a safety perspective. This study entailed the analyses of safety-related data from all of the TravTek empirical studies which included the Rental User Study, Local User Study, Yoked Driver Study, Orlando Traffic Network Study, and the Camera Car Study. These studies provided vehicle collision data, driver/vehicle performance measures, observer measures, and driver subjective measures.

The objectives of the Safety Study were to determine:[1,2]

a. If the users of the TravTek system as deployed in Orlando experienced a different level of safety than drivers of comparable vehicles without the TravTek system.

b. How the different TravTek configurations affected the safety experience of the drivers.

c. How the safety experience as observed in Orlando for the 100 vehicle deployed in the operational field test would change as a function of the level of market penetration as the system becomes more widely deployed.

In order to meet the above objective, a Safety Study methodology was developed that included the following four analytical steps.

Analyses of Facility and Traffic Volume Effects on Base Accident Rates

This step presents a review of the literature and analyses for establishing the impact of traffic congestion on accident rates. The analysis considers the correlation that exists between traffic volume and facility type. The results of these analyses were used to establish risk factors associated with levels of congestion as a function of facility type for use in INTEGRATION modeling. [3]

This analytical step addressed the first objective of the TravTek Safety Study. The results indicate that the national crash rate of 1.74 crashes per million veh-km (2.8 crashes per mvm) traveled varies considerably as a function of facility type and other variables. This variance ranges from a low rate of 0.33 on urban Interstates to a high rate of 5.26 crashes per million veh-km (8.464 crashes per mvm) on rural local roads. The former urban Interstates only represent 0.30 percent of all road mileage by carry nearly 13 percent of all vehicle km. The latter local roads represent nearly 55 percent of all road km, but only 4.5 percent of all vehicle km. Crash rates on rural roads were found to be 6 times as high as on urban roads. Furthermore, the accident rates, when expressed in crashes per million veh-km for urban roads, were found to range from 0.33 to 1.08, 1.536, 1.539, and 2.12 for Interstates, other principal arterials, minor arterials, collectors, and locals, respectively. The implication of the above finding is that it is more appropriate that any TravTek accident rates should be compared to the urban national average crash rate of 1.197 crashes per million veh-km, rather than the combined rural and urban value of 1.768. It also indicates that the hierarchical routing algorithm within the TravTek vehicle, which favors higher class roads over lower class roads, is desirable from a safety point of view. This desirability arises from the fact that the former road classes are 3 to 5 times as safe per vehicle-km as the latter.

The examination of traffic effects has indicated that there is a positive correlation between traffic volume and accident rates for arterials. It also indicates that there is a negative correlation for freeways prior to the onset of congestion. However, the latter freeway accident rates are shown to increase by a factor ranging from 2.0 to 3.0 when queues develop. The difference in the finding for freeways as opposed to arterials may be attributed to the fact that queues are always present at traffic signals. However, as the traffic volumes increase these queues gradually become more prevalent---but their presence is never a sudden occurrence. On the other hand, on freeways, the initial increase in traffic volume prior to the onset of queuing has an effect of reducing the variability in speeds. This reduction in turn may reduce the accident rate until queues form. When queues form, the speed differences increase dramatically, and hence cause a dramatic increase in the accident rates.

Evaluation of TravTek Operational Test Incidents and Accidents

This step presents a description of the incidents and accidents that occurred during the TravTek Operational Test that involved TravTek vehicles. The incident statistics are compared against data provided by AVIS for the US and Orlando fleets of non-TravTek vehicles. Exposure values are estimated for Renters, Local Drivers, Drivers in Controlled Field Studies, and Evaluation Personnel. The accident statistics for these groups are compared against national statistics. In addition, detailed analyses are presented for accidents involving crashes.

The entire population of drivers in TravTek drove approximately 1 887 977.77 km during the 10 month test phase of the program. The use of crash data to assess the impact of roadway treatments on safety generally requires multiple years of crash data to be recorded. In TravTek, data were collected for a 10-month period for a small fleet of vehicles (small for this type of analyses technique). The methods presented in this report provide a technique for assessing the safety impact of in-vehicle displays; however, the study suffers from a lack of data with respect to exposure.

The review of the crashes and incidents in TravTek suggests that the system did not pose a serious safety problem. For the entire population of test drivers there were three crashes (Renters, Local drivers, and drivers in the System Effectiveness Studies). Two of these crashes involved TravTek vehicles that were stopped in private parking facilities when they were struck by another vehicle. None of the test drivers mentioned the TravTek system in their accident report forms.

The majority of crashes during the 10-month operational test were for the drivers in the Other category. This category included VIP's, experimenters, AVIS personnel, and TravTek partners who were testing the capabilities of the system.

Statistical analyses of the TravTek crash data showed that the crash rates for the different studies did not significantly differ from an adjusted population crash rate. That is, crash history for the drivers in the Field and System Effectiveness Studies suggests that the TravTek system did not have a negative impact with respect to safety.

Estimation of Potential Safety Impacts of TravTek In-Vehicle Devices

This step summarizes and integrates the results of the Field (Rental and Local User Studies), and System Effectiveness (Yoked Driver Study, Orlando Traffic Network Study, and Camera Car

Study) Studies to estimate the potential impact of TravTek in-vehicle systems on safety. The analyses presented under this step rely heavily on the use of driving performance, observational, and subjective data. These are measures such as speed variability, lane deviation, eye glance (off-road) frequency and duration, perceived workload, near misses (reported by observers), and abrupt maneuvers. The analysis draws upon the results of the field and system effectiveness studies to establish functional relationships between accident risk and such factors as display type, experience with the traffic network, experience with the TravTek system, and driver age.

The results showed that the Turn-by-Turn display was safer than the Route Map display, and configurations with voice were estimated to be safer than those without voice. The Camera Car Study results showed that there were more safety-related errors (near misses) in the TravTek route map without voice condition than currently used methods for navigating (e.g., Paper Map). Also, experience with the use of the TravTek system was estimated to have a potential for increasing safety.

The results of this third analytical step were integrated with the results of the analyses of TravTek incidents and crashes to derive an estimate of the impact of TravTek in-vehicle devices on safety. These estimates are employed in the INTEGRATION modeling where sensitivity trade-off analyses were performed. That is, potential impacts associated with route guidance, navigation, and congestion avoidance were traded-off against the potential impacts associated with use of in-vehicle devices.

Modeling the Potential Safety Impacts of TravTek

This analytical step presents the results of INTEGRATION modeling studies. The modeling studies served to “integrate” the results of the previous analytical efforts. Potential safety impacts of TravTek-like systems were investigated under varying levels of market penetration and traffic demand. Measures of effectiveness with respect to risk were computed. The results showed a significant main effect for level of traffic demand on accident risk, as level of traffic demand was increased (increased congestion) accident risk was increased. There was an interaction between level of traffic demand, level of market penetration , and Advanced Traveler Information System (ATIS) equipped versus non-equipped vehicles. At low levels of market penetration and low levels of traffic demand, the equipped vehicles had lower safety risk relative to the non-equipped vehicles. However, at the low levels of market penetration (less than 30 percent) and high levels of traffic demand (10 percent greater than average demand at 6:00 p.m. peak) the ATIS-equipped vehicles were shown to have a higher safety risk relative to the non-equipped vehicles. At higher levels of market penetration (greater than 30 percent) there was not a reliable difference in risk between the ATIS- equipped and non-equipped vehicles.

The modeling studies showed the interaction between congestion, facility type, and diversions about congestion on safety risk. For the Orlando traffic network, diversions away from congestion present on freeways will involve driving on arterials or lower class roads. In the Orlando traffic network there is not the possibility of freeway to freeway diversions. The TravTek routing logic is such that it places the vehicle on higher level facilities if possible for a trip. Therefore, trips generally start on lower class roads, increase to higher class roads (e.g., freeways), and do not divert from the higher class road until required to reach the destination. Under levels of low traffic demand, therefore the ATIS equipped vehicles will remain on the freeways and will experience a lower level of risk relative to the background traffic. The background traffic is expected to use lower class road relative to the ATIS equipped vehicles under level of low traffic demand. When demand is higher, but no congestion exists that leads to diversions, the ATIS equipped vehicles experience a level of risk nearly equivalent to the background traffic However, at levels of high traffic demand where diversions due to congestion will occur, the ATIS equipped vehicles will experience a higher level of risk relative to the background traffic due to their greater level of diversion on to lower, and riskier, class roads. This effect of increasing risk for the ATIS equipped vehicles due to diversions to avoid congestion, disappears as the level of market penetration goes beyond 30 percent.

The TravTek system is a distributed architecture where the vehicles receive network travel time information from the Traffic Management Center (TMC) and optimize their own individual travel times However, there is a feedback loop between the TravTek vehicles and the TMC in that the vehicles transmit probe reports to the TMC which are subsequently used to compute travel times for transmission by. the TMC. To understand the impact of this architecture feature and the fact that the TravTek vehicles do not tend to divert when congestion is not present, one needs to consider two cases in a simultaneous manner: (1) low level of market penetration and high traffic demand (congestion will be present); and (2) high level of market penetration and high traffic demand. When there is a high level of market penetration, the feedback loop between the vehicles and the TMC will result in a smaller proportion of equipped vehicles diverting from the higher class roads. That, is after a large number of vehicles are diverted to a lower class road to avoid congestion, this diversion route will also become congested or not present more advantageous travel times relative to non-diverting. The updated travel times from the TMC will reflect the impact of the diversion of traffic (both equipped and non-equipped) on the diversion route. On the other hand, when market penetration is lower, the feedback loop between the vehicles and the TMC is such that a greater proportion of equipped vehicles will divert from the higher class roads and thus incur a higher risk relative to the background traffic. In other words, at lower levels of market penetration the TravTek equipped vehicles will divert a greater proportion of time relative to the background traffic.

SUMMARY

Analysis of incidents and accidents indicated that the TravTek vehicles did not impose an added safety risk. The analysis of incident and accident data suffered from the fact that there were relatively few miles driven and few incidents and accidents were observed. In order for a methodology that uses accident data to have a chance of observing a negative or positive effect on safety due to the introduction of an in-vehicle system or other manipulations (e.g., changes to road design), significantly more km of exposure would be needed. If anything, the methodology used for examining accident and incident data is more likely to find a negative effect rather than a positive one due to the statistical properties of the analysis.

Review of the results from the Field and System Effectiveness Studies showed that different configuration of the in-vehicle system presented different levels of risk. Analysis of estimates of safety risk such as number of near misses and number of safety-related errors when a hazard was present showed that when driving with the route map display, drivers had about twice as many near misses and safety-related errors relative to the other conditions. It should be noted that drivers in the Paper Map condition tended to drive from a memorized route, and were shown to make significantly more stops than drivers in TravTek equipped vehicles. These drivers tended to stop when they needed route directions. The TravTek Turn-by-Turn display with voice augmentation was shown to have a low level of safety-related distraction that was at about the same level as when driving a memorized route. Individual safety-related measures, such as lane deviations, glance durations in excess of 2.5 s, and abrupt longitudinal maneuvers showed similar trends; Turn-by-Turn with voice augmentation being among the best and route-map without voice augmentation consistently being the worst of all conditions.

Number of wrong turns while traveling to a destination, a performance measure that is not apparently directly related to safety risk, was also analyzed as part of the Safety Study. Analysis of this measure showed that drivers with TravTek made significantly fewer wrong turns relative to drivers in non-TravTek vehicles. The probability of making a wrong turn was estimated for TravTek equipped ‘and non-equipped vehicles and used as input for the modeling studies with INTEGRATION. Making wrong turns, on the average, increases trip distance and time. This measure was shown to have a significant impact on safety risk when employed in the modeling studies. The fact that TravTek drivers tend to make fewer wrong turns than the background traffic, on the average, yields a safety benefit to the TravTek drivers.

The modeling study showed an interaction between level of market penetration and level of traffic demand on predicted accident rates. The predicted safety effects for the TravTek system were also shown to be dependent on the nature of the traffic network and the system architecture (e.g., distributed logic for routing of vehicles based on real-time information). At low levels of market penetration, a TravTek like system is predicted to have positive safety effects for equipped vehicles at low levels of traffic demand. At high levels of traffic demand, due to the diversion from high class roads in response to congestion, the equipped vehicles are predicted to incur additional safety risk. However, at higher levels of market penetration the level of risk for TravTek equipped vehicles is nearly equivalent to that of the background traffic. The report by VanAerde et al. presents modeling results where the impact of TravTek on fuel consumption, travel time, and emissions are examined. [3] This modeling report predicts significant benefits for the TravTek system in terms of the above measures. Overall, the system is shown to provide benefits for most measures while also resulting in trade-offs in terms of safety risk.

INTRODUCTION

Advanced Traveler Information Systems (ATIS) make travel more efficient and safer. Efficiency would be derived through the employment of navigation, route planning, route following, and real-time traffic information. Drivers will be less likely to get lost, will plan more efficient trips, and will avoid incidents and congestion. Furthermore, depending on the system architecture, network-wide benefits will be realized in terms of efficient traffic flows that will benefit ATIS as well as non-ATIS equipped vehicles.

ATIS also present the capability of making travel safer. ATIS is envisioned to have multiple components that will be interrelated: [4]

- In-Vehicle Routing and Navigation Systems (IRANS).
- In-Vehicle Motorist Services Information Systems (IMIS).
- In-Vehicle Signing Information Systems (ISIS).
- In-Vehicle Safety Advisory and Warning Systems (IVSAWS).

Some of the components envisioned for ATIS could have a direct impact on driving safety. For example, IVSAWS could provide drivers early warning of roadway hazards such that drivers will be better prepared to respond in a safe manner. On the other hand, IRANS would provide drivers with navigation and route guidance information, perhaps supplemented with real-time traffic information. These capabilities can increase safety by allowing drivers to concentrate their resources on driving tasks, especially when driving on unfamiliar routes. Rather than employing Paper Maps or written directions which may result in long and frequent glances away from the roadway, a well designed IRANS can provide drivers with the required information in a safe and easy to use manner.

ATIS also present the potential of negatively impacting driving safety. It gives drivers information that they need in different ways than is currently presented. There is a wide range of options for developing and designing specific ATIS interfaces. The driver-ATIS interface will be critical in defining the degree to which driving safety will be maintained or enhanced. A poorly designed ATIS interface that overloads the driver with information, promotes long and frequent glances away from the roadway, and requires extensive driver intervention while the vehicle is in motion may serve to increase risk. [5]

The TravTek Operational Test was designed to evaluate a wide range of variables that included efficiency (e.g., decrease in travel time) and safety impacts associated with the implementation of a given ATIS design. [2] Also, experiments were performed to explore the safety and ease of use of subcomponents of the system. TravTek presents a subset of the elements envisioned for a full-up ATIS. It contained IRANS and IMIS elements. The system provided navigation, route guidance, real-time traffic information, and area wide information data base. These elements were integrated in the vehicle such that route selection employed real-time traffic information. [6]

TRAVTEK SYSTEM OVERVIEW

The TravTek system architecture was composed of three primary components: the TravTek vehicles, the TravTek Information and Service Center (TISC), and the TMC. These three components are described briefly in this section. The reader may refer to Rillings and Lewis for additional details. [(6)] Figure 1 provides a graphical overview of the TravTek system architecture. In the figure, data links are indicated by arrows. It can be seen that the vehicle both received and transmitted data. Data transmitted by the vehicle included travel times across TravTek network roadway segments.

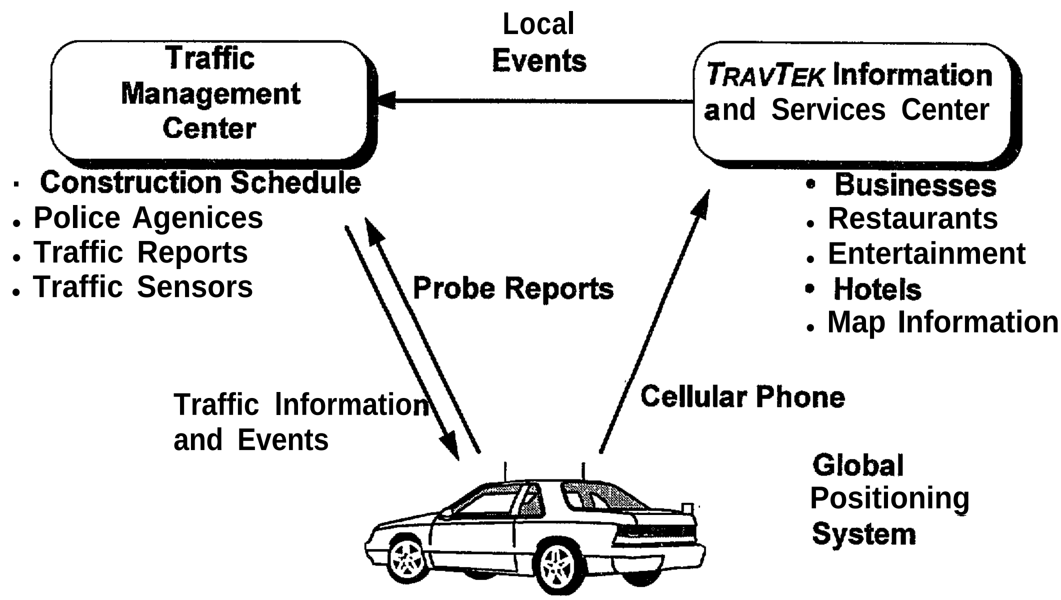


Figure 1. Overview of the TravTek system.

TravTek made a wealth of information available to drivers. This information included: route planning; Turn-by-Turn route guidance; real-time traffic reports; and real-time traffic information inputs to route planning. Some of the features of the TravTek system are:

- **Navigation —** A variable-scale color map was displayed on a 128-mm (5-in) video display. The video display, an option on the Oldsmobile Toronado, was positioned high on the dashboard and to the driver's right. The Navigation system used a combination of dead-reckoning, map-matching, and Global Positioning System information to indicate the vehicle's position on the map. The vehicle's position was indicated by a horizontally centered icon positioned three-fourths of the distance from the top of the screen. When the vehicle was in DRIVE the map was always displayed with a heading-up format.

- **Route Selection —** An in-vehicle routing computer provided the minimum-time route from the vehicle's current position to a selected destination. The minimum-time criterion was subjected to constraints such as turn penalties, preference for higher level roadways, and avoidance of short-cuts through residential areas.

- **Route Guidance —** When a route had been computed, a sequence of guidance displays provided maneuver-by-maneuver driving instruction. The visual guidance display could be augmented by synthesized voice that provided the next turn direction, distance to the turn, and the name of the street on which to turn. The driver could switch between the maneuver-by-maneuver *Guidance Display* and a *Route Map.* The Route Map showed the planned route as a magenta line traced over the Navigation display (described above). Buttons on the steering wheel hub were used to swap between the Guidance Display and the Route Map and to turn the voice guidance function off or on. An illustration of the Guidance Display is provided in figure 2. An illustration of the Route Map is provided in figure 3. Should the driver deviate from the planned route, an OK NEW ROUTE button was provided on the steering wheel hub. The TravTek system always offered drivers the opportunity to select a new route whenever it detected that they had deviated from the planned route. The new route took into account the vehicle's present location and heading and thus took into account that the previously planned route might not be the best one given the new circumstances.

- **Real-time Traffic Information —** Real-time traffic information was broadcast to TravTek vehicles once every minute. To limit the quantity of information broadcast, only exceptions to normal traffic flows were reported. The real-time information could be used in route planning. Also, if conditions changed while the vehicle was en route, a new, faster route could be offered to the driver.

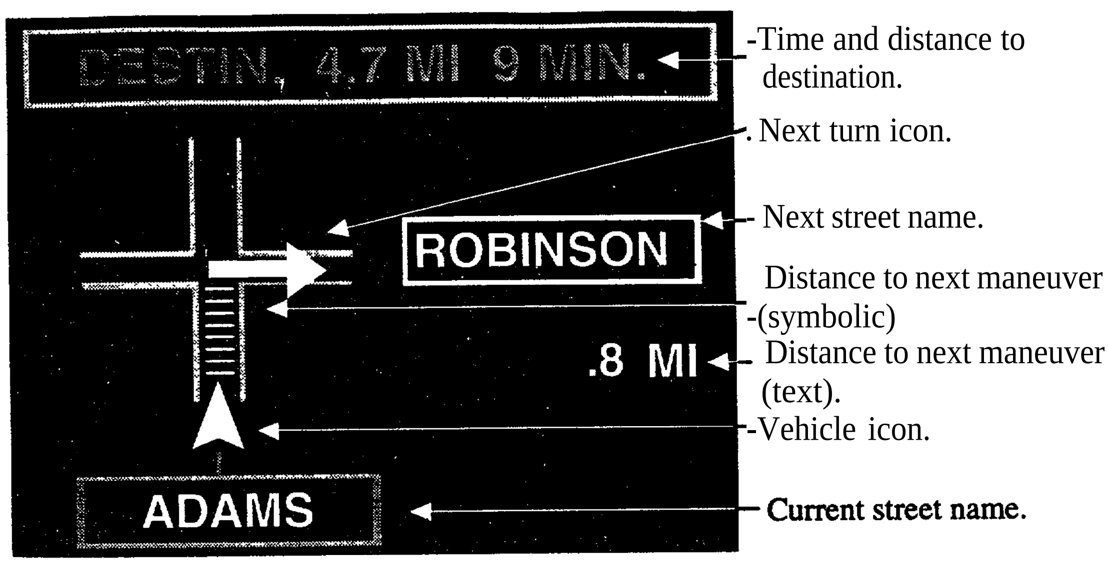


Figure 2. The TravTek Guidance Display. (6)

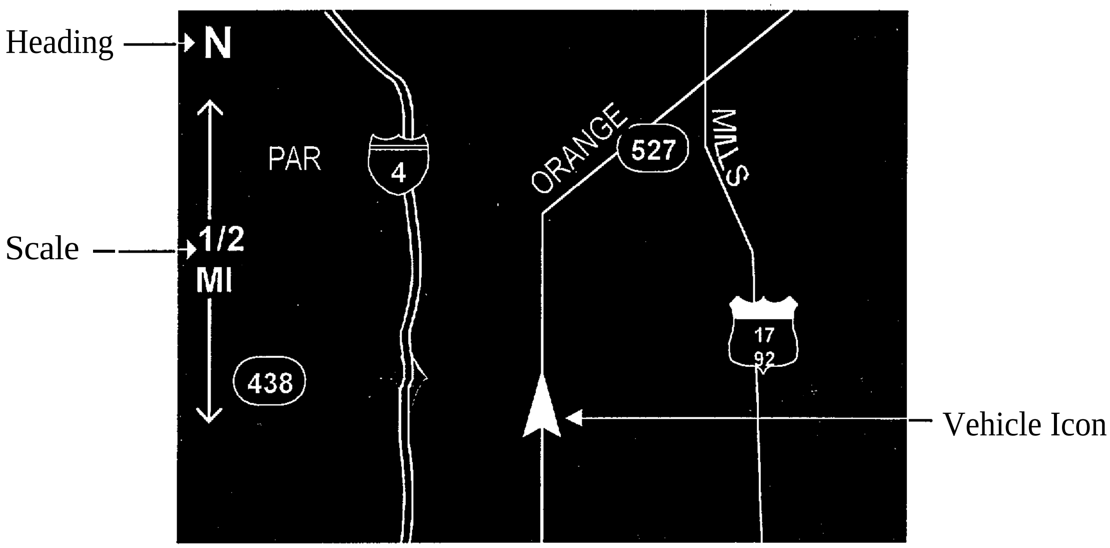


Figure 3. The TravTek Route Map displays the planned route as an overlay on the heading up map display. (6)

- **Help Desk Telephone Assistance —** When the vehicle was in PARR, a *HELP* function was available by pressing a touch sensitive key on the video display. One feature of the HELP function was free cellular telephone calls to the TISC.

  The TISC was operated by the American Automobile Association. Help desk operators had access to a TravTek simulator that replicated the TravTek functions available to the driver. This enabled the TravTek operators to replicate problems encountered by drivers, or to plan routes just as they are planned in the vehicle.

Figure 4 provides an overview of the TravTek in-vehicle architecture. Compass, wheel sensor, and Global Positioning System data were used by the navigation computer to position the vehicle relative to a map data base. A second computer, the routing computer, used a different data base to plan routes and to provide navigation assistance. The routing computer also maintained a data log that is described in the Methods section. The driver could interact with the system via touch sensitive buttons on the video display, steering wheel buttons, and buttons on the video display bezel.

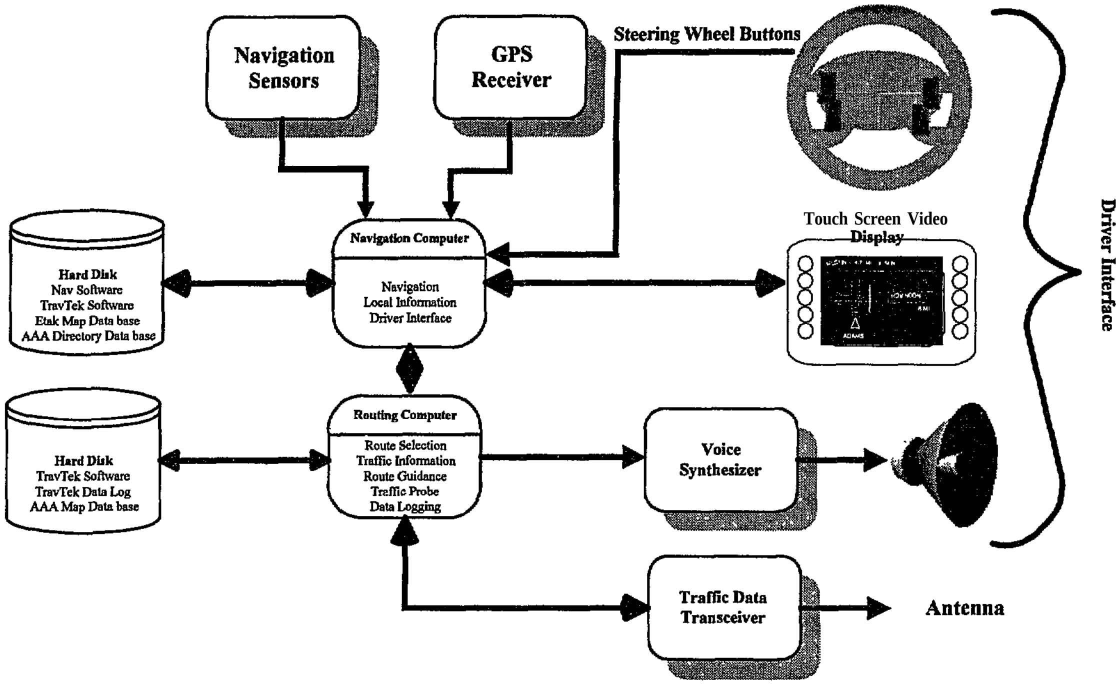


Figure 4. Schematic representation of the TravTek vehicle architecture.

TravTek Experimental Configurations

The TravTek system was designed to fully support the conduct of field research. Unlike an ATIS product-level system, the TravTek system provided capabilities for logging driver/system performance data in addition to providing the services described earlier (e.g., route guidance, navigation). The system was also designed to support the configuration of alternative systems presenting varying levels of capabilities to the drivers. The following were the three main alternative configurations used in the operational test:

Services (S) Configuration: This was an experimental control, or baseline condition for evaluating navigation and route guidance provided by the other configurations. Accordingly, it provided neither navigation nor route guidance information. This configuration only provided IMIS capabilities to the drivers that could be used while the vehicle was parked.

Navigation (N) Configuration: This configuration provided all of the features in the S configuration as well as navigation and routing options based on in-vehicle storage of nominal travel times.

Navigation Plus (N+) Configuration: This configuration provided all of the features of the N configuration plus the addition of real-time traffic information which was employed in the routing algorithm.

TravTek Empirical Studies

The TravTek Operational Test included the conduct of five separate empirical tests. The following presents a brief overview of each of these empirical studies. Detailed descriptions of the methods, procedures, and results of these studies are presented in separate study reports.

Rental User Study

This included the participation of visitors to the Orlando, Florida area. The drivers were recruited by AAA from their club membership. The study employed the S, N, and N+ configurations described above. Safety data from this study included incidents and crashes, and driver subjective impressions about the impact of TravTek on safety.

Local User Study

This study included the participation of Orlando residents that were high mileage drivers. The drivers in this study drove N and N+ equipped vehicles for approximately 2 months. In addition, a subset of the drivers in this study participated in the Camera Car Study. Safety data from this study included driver subjective impressions about the impact of TravTek on safety.

Yoked Driving Study

This study included the participation of visitors to the Orlando, Florida area. The drivers were run in a controlled field experiment that included the S, N, and N+ configurations. The drivers were run in yoked triads over three selected Origin/Destination (O/D) pairs to evaluate the impact of route guidance on navigation and real-time traffic information of congestion avoidance. The study included an in-vehicle observer. Safety data from this study included observer recorded close calls, subjective workload ratings, and driver subjective impressions about the impact of TravTek on safety.

Orlando Test Network Study (OTNS)

This study included the participation of visitors to the Orlando, Florida area. The study employed the N configuration. However, six different display configurations were formed as follows: (a) Turn-by-Turn display with voice; (b) Turn-by-Turn display without voice; (c) Route Map display with Voice; (d) Route Map display without voice; (e) no visual electronic navigation display and Paper Map with Voice; and (f) no visual electronic navigation display and Paper Map without voice. The same O/D pairs used in the Yoked Driver Study were employed in this study. The study included an in-vehicle observer. Safety data from this study included observer recorded close calls, subjective workload ratings, and driver subjective impressions about the impact of TravTek on safety.

Camera Car Study

The Camera Car Study included two separate evaluations that employed different subject populations. The first study entailed the participation of visitors to Orlando that had not been previously exposed to TravTek. The second study employed drivers from the Local User Study. These drivers were tested during the beginning and end of their driving experience. The same O/D pairs used in the Yoked Driver Study and OTNS were employed in this study. The study included an in-vehicle observer. Safety data from this study included observer recorded close calls, subjective workload ratings, video recorded data, vehicle/driver performance data (e.g., steering deviation), and driver subjective impressions about the impact of TravTek on safety.

PURPOSE OF TEST

With respect to safety "the underlying hypothesis of the TravTek design is that drivers with TravTek will be able to navigate better than drivers who do not have TravTek. If this is true, TravTek drivers should have a more worry-free and safer driving experience because they would be routed around congestion and delay-causing incidents, and should therefore spend less time being lost or confused about location. The counter hypothesis is that drivers might need to devote so much time and attention to obtaining the necessary information that safety could decrease. The purpose of the safety component of the evaluation is to address these two sides of the safety question." (1)

The objectives of the Safety Study were to determine: (1,2)

a. If the users of the TravTek system as deployed in Orlando experienced a different level of safety than drivers of comparable vehicles without the TravTek system.
b. How the different TravTek configurations affected the safety experience of the drivers.
c. How the safety experience as observed in Orlando for the 100 vehicles deployed in the operational field test would change as a function of the level of market penetration as the system becomes more widely deployed.

The above objectives are interrelated and need to be examined in an integrated manner. The approach employed for the TravTek safety evaluation uses modeling to combine the results of multiple experimental and analytical studies. The INTEGRATION model was used to integrate results from the statistical modeling, driving performance studies, and the vehicle's routing logic.(3) Modeling studies using INTEGRATION were conducted to examine the trade-off between safety costs and benefits.

CONCEPTUAL APPROACH

The overall safety impact of an ATIS system such as TravTek is considered to be made up out of the interaction of two related components. The first component captures the differential impact on safety of having the same driver travel the same route under similar conditions one time with and one time without an ATIS system onboard. This factor is referred to in this report as the "gadget factor" effect, as it captures primarily the impact of having the ATIS device present in the vehicle. The second component captures the safety impact of the fact that the ATIS may at certain times route a driver away from his/her regular route to an alternative route. This alternate route. is usually expected to be faster. However, due to its geometry, level of congestion, or type of access control may also have different safety characteristics than the route that the driver was traveling on initially. This latter component is referred to in this paper as the "routing factor" as it captures safety impacts that arise from the route that is selected. This effect may be independent of the safety attributes of the "gadget" or medium by which these routes are conveyed to the driver. A brief discussion of the factors, which may influence the potential sign and magnitude of the impacts of both the routing factor and the gadget factor, is provided next. This discussion is provided in order to place the overall analysis of this report in its appropriate context.

Factors Influencing the Impact of the Gadget Factor

The gadget factor is intended to reflect the differential safety impact of having the ATIS gadget present, active and being utilized in a vehicle. The potential negative aspects of the gadget factor could derive from the fact that the drivers may perhaps be distracted from their regular driving task by either physically looking at the display and/or by mentally allocating time towards interpreting the instructions or information that are provided. Furthermore, if the route guidance component sends the vehicle down a new route, the driver may be less familiar with that new route. This unfamiliarity in turn may lead to a decrease in safety when compared relative to a driver who travels this same route but one who is familiar with it. This impact would primarily apply to commuters, as tourists are likely to be unfamiliar with any of the potential routes. Furthermore, even commuters who are diverted to an alternative route may be somewhat familiar with the alternative routes, even though they would not have considered them faster, if they had not been proposed by the ATIS.

On the positive side, the presence of the on-board unit may substitute for, for example, a paper source of guidance information. The use of Paper Maps or direction lists may present a level of distraction that increases risk relative to the use of an ATIS device. Furthermore, an ATIS device can provide advance notice of downstream traffic congestion and/or turning movements. This can result in an improved preparation of the driver for executing the appropriate lane changing, speed changing or simple turning maneuvers in a less abrupt manner. Some have even suggested that simply the improved knowledge of the source and the duration of any congestion that may be experienced, can result in a less stressful driving experience. Such an effect may be present even if no actual diversion away from the congestion can take place. Such less stressful driving may therefore also provide a further safety benefit.

The above examples indicated that there may be both positive and negative aspects to the potential net safety impacts of having an ATIS device in a driver's vehicle. These impacts indicate that the presence of a such a device may by itself be neither strictly more nor less safe. Instead, the net effect is likely to be a complex function of how each of the above factors offset or counter balance each other. Furthermore, such counter balancing is likely to be somewhat dependent upon the particular driver, route and/or specific driver interface. Commuters vs. recreational drivers may also have different base safety levels, while for a given driver the counter balancing effects may be dependent upon the prevailing level of traffic congestion.

The Routing Factor

The routing factor essentially parallels, yet complements, the impacts of the above gadget factor. As indicated earlier, it focuses exclusively on the relative safety impact of utilizing an alternative route. Such effect is independent of what mechanism may have initially lead to the selection or use of this alternative route, or what medium may have been utilized to convey the route to the driver. The routing factor impact is therefore defined such that the safety impacts of the presence of a gadget (that may have initially recommended the alternate route, or which continues to assist the drivers in their navigation task along the alternative route), are not considered or double counted.

In the first instance, the use by commuters of a diversion route in order to avoid traffic congestion will typically result in a longer distance exposure but a shorter time exposure to any safety risk. However, the use of an ATIS device by non-commuters will likely result in a reduced level of exposure for both measures. The exact magnitude of each exposure difference is likely highly network and driver dependent, yet may be determined quite accurately by examining samples of the routes taken by each type of driver. The routing factor is defined, calibrated and expressed per unit of exposure and is multiplied against an externally determined measure of the differential level of exposure, in order to determine the net routing effect.

It should be noted that some literature has examined the theoretical appropriateness of utilizing various different safety exposure measures. However, as the number of vehicle-miles traveled is virtually the only exposure measure which in most cases is practically available, with any level of consistency, it is the exposure measure that is utilized virtually exclusively in the following safety analysis.

As defined herein, the routing factor captures primarily any difference in the level of risk (per unit of exposure). This difference arises due to the alternative route being of a different facility type, which may or may not also be concurrently experiencing a different level of traffic congestion. The factor therefore explores the question of whether a diversion, which results in the use of an alternative facility type, will on average be associated with an intrinsically lower or higher risk per unit of exposure. The overall routing effect then examines if this reduced risk rate can compensate for the potentially additional distance exposure that is typically encountered by commuters during the diversion, and any gadget effect.

Illustrative Hypothetical Example

In order to illustrate the use, concept and differences of the above factors, consider the following simple hypothetical example. In this example two drivers are each 10 km from home on their regular route that is entirely along a freeway. The remaining portion of their trip would, in the absence of any congestion, typically take 8 min. The best alternative route is a 15 km long arterial, which when uncongested would require 15 min to traverse. On the day of interest, an incident has occurred on the remaining portion of the freeway that has made it congested such that the new freeway travel time is now 20 min.

If the freeway accident rate is 1 accident per million veh-km during uncongested conditions and 5 accidents per million veh-km when congested, the accident risk for the driver that remains on the freeway would increase from 0.000,0l0 to 0.000,050. This risk is expressed as the probability of being involved in an accident. If the arterial has comparable congested and uncongested accident risks of 2 and 4 accidents per million veh-km, the driver who diverts to the arterial would experience a risk of 0.000,030 or 0.000,060 instead. It would therefore appear that, if the arterial remained uncongested, that it would also become the safer route to take, even though it involved a longer amount of safety exposure (12 versus 10 km). However, if the arterial also became congested, the congested freeway would remain safer than the arterial, even though the risk per unit of exposure on the freeway was higher.

The above analysis implicitly considered that the net gadget factor was essentially safety neutral. The magnitude of the gadget factor could actually have been up to a value of 1.66 (= 0.000,050/ 0.000,030) before it would have made the uncongested arterial less safe. However, the factor would need to have been less than 0.83 (=0.000,050/0.000,060) before it would have made the congested freeway route less safe than the congested arterial. The above example also requires, of course, that the gadget factor effect is insensitive to the level of traffic congestion that is being encountered.

The above hypothetical example illustrates the following important issues. In the first instance, the relative change in the safety level of utilizing one route versus an alternate is a function of both the additional length of this diversion route, the base difference in the per unit exposure safety risk of one facility versus the next, and the magnitude of the traffic congestion impact on safety for both facility types. Secondly, if the safety impact of the routing factor is sufficiently positive, it may potentially offset any moderately negative gadget effects or increased exposure effects, should these be found to exist.

TECHNICAL APPROACH

Figure 5 presents an overview of the technical approach employed for the Safety Study. There were four major analytical steps in the technical approach. The following presents a discussion of the analytical steps followed in the study.

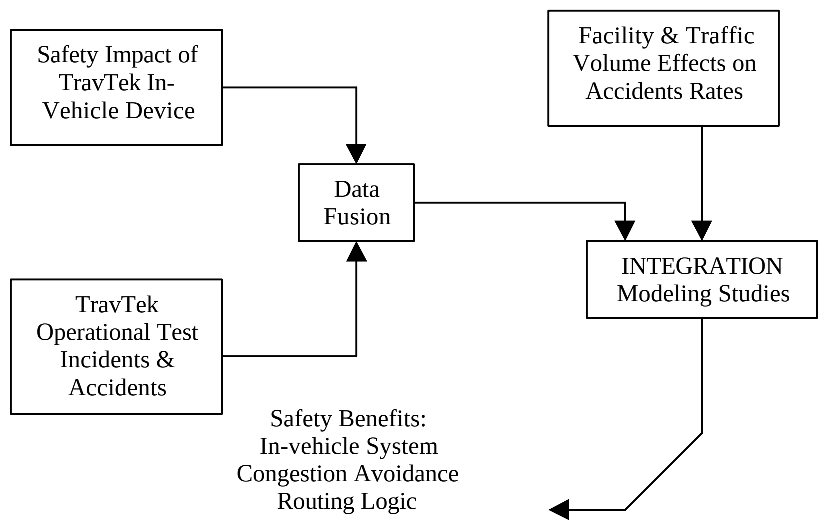


Figure 5. Overview of Safety Study technical approach.

Analyses of Facility and Traffic Volume Effects on Base Accident Rates

This step presents a review of the literature and analyses for establishing the impact of traffic congestion on accident rates. The analysis considers the correlation that exists between traffic associated with levels of congestion as a function of facility type.

This analytical step addressed the first objective of the TravTek Safety Study. This step results in regression equations used to estimate risk as a function of facility type and level of congestion.

Evaluation of TravTek Operational Test Incidents and Accidents

This step presents a description of the incidents and accidents that occurred during the TravTek Operational Test that involved TravTek vehicles. The incident statistics are compared against data provided by AVIS for the US and Orlando fleets of non-TravTek vehicles. Exposure values are estimated for Renters, Local Drivers, Drivers in Controlled Field Studies, and Evaluation Personnel. The accident statistics for these groups are compared against national statistics. In addition, detailed analyses are presented for accidents involving crashes.

Estimation of Potential Safety Impacts of TravTek In-Vehicle Devices

This step summarizes and integrates the results of the Field (Rental and Local User Studies), and System Effectiveness (Yoked Driver Study, Orlando Traffic Network Study, and Camera Car Study) Studies to estimate the potential impact of TravTek in-vehicle systems on safety. The analyses presented under this step rely heavily on the use of driving performance, observational, and subjective data. These are measures such as speed variability, lane deviation, eye glance (off-road) frequency and duration, perceived workload, near misses (reported by observers), and abrupt maneuvers. The analysis draws upon the results of the field and system effectiveness studies to establish functional relationships between accident risk and such factors as display type, experience with the traffic network, experience with the TravTek system, time of day (day versus night) and driver age.

Data from this analysis step and the evaluation of TravTek incidents and crashes are integrated to derive composite risk factors for INTEGRATION modeling studies. The data fusion process relies on subject matter expert input to derive weighted functions that combine crash data, driver performance data, observer data (e.g., observed close calls), workload data, and driver subjective responses and result in single integrated risk scores. Integrated risk scores are derived as a function of TravTek configuration, visual display type (Route Map or Turn-by-Turn), Voice display (Voice on or Voice off), local versus visitor to the Orlando area, level of experience with TravTek, driver age, and time of day (day versus night).

Modeling the Potential Safety Impacts of TravTek

This analytical step presents the results of INTEGRATION modeling studies. The modeling studies served to “integrate” the results of the previously described analytical efforts. Potential safety impacts of TravTek-like systems were investigated under varying levels of market penetration. Measures of effectiveness with respect to risk avoidance were computed. The modeling study allowed the investigation of the impact of the “gadget factor” and the “routing factor” on safety in an integrated manner. Estimation of the system safety impact of ATIS entails the joint consideration of these two factors. Potentially ATIS could be designed that are safety neutral or safety positive with respect to the driver interface (gadget factor); however, the system may provide unreliable rerouting information and choose non-optimal (e.g., shortest time or distance) routes and result in a negative system safety impact. The inverse of this example could also be true where the driver system interface is a safety detractor.

Each of the above analytical steps are discussed in detail in the following sections of the report. The report concludes with an integrated safety assessment of the TravTek system and recommendations for future operational ITS safety evaluations are provided.

FACILITY AND TRAFFIC VOLUME EFFECTS ON BASE ACCIDENT RATES

One of the major components of the overall benefit assessment of an ATIS such as TravTek is an analysis to determine the safety implications of the use of this type of system. Such safety implications can be explored to some extent through the analysis of safety-related data obtained directly from the actual driving experiences of the users of prototype systems that were deployed. However, many other implications can only be explored through an examination of other related safety data and literature, much of which is not necessarily ATIS specific. This section focuses specifically on an analysis of non-TravTek sources of safety data and literature.

This section of the report will review some standard reference statistics on the safety experience on North American roads to provide a context within which the subsequent analyses can be examined. The impact of facility type on safety based on nationwide accident statistics for urban and rural Interstates, arterials, collectors and local roads is also examined. This section also explores how changes in the level of traffic flow and congestion on each of these facilities may modify the base accident rates on each facility.

This section provides an additional discussion of literature on the impact of incidents, geometries, etc. on accident rates and summarizes the recommended accident rate model values. Also, data collected from the Orlando Freeway Management Center (FMC) on I-4 are used to calibrate the model values used in INTEGRATION. The development of statistical models capturing the relationship between facility type, level of congestion, and accident rates relies on data from the literature as well as empirical results from the TravTek Operational Test.

BACKGROUND AND NOMENCLATURE

In order to assist the interpretation of the TravTek-specific safety data (for purposes of deriving an estimate of the gadget factor, as well as to assist the interpretation of the various data bases and literature sources for purposes of deriving a routing factor), this section of the report provides a general overview of the accident experience in the United States of vehicles which are not equipped with an ATIS device. Specifically, the impact of different accident reporting standards, of under reporting of accidents, of time-of-day effects, and multiple vs. single vehicle accidents are presented.

An Overview of Recent Police-Reportable Crashes in the United States

One of the most comprehensive sources of the national accident experience is provided in an annual report that is generated by the National Highway Traffic Safety Administration. Their General Estimates System (GES) reports that in 1991 there were a total of 6,110,OOO police-reported motor vehicle traffic crashes in the United States. [(7)] Based on FHWA estimates, in this same year there were 3.49 trillion veh-kms (2.17 trillion veh-mi). [(8)] This results in a crash rate of 1750 crashes per billion veh-km (28 16 crashes per billion veh-mi) driven. This average is a global value for all vehicle types combined and not exclusively for passenger cars, as will be further discussed later.

As this total crash number is a sum of both single and multiple vehicle accidents, it should be noted that these 6,110,OOO crashes involved a total of 10,619,000 vehicles, or approximately an average of 1.6 vehicles per crash. The average national vehicle involvement rate is therefore actually 3041 vehicles per billion veh-km (4894 vehicles per billion veh-mi) traveled. From a highway authority point of view, the former number of crashes is usually the preferred safety indicator, as they are interested primarily with how many accidents will occur. However, from a driver's point of view, the latter risk of vehicle involvement is somewhat more relevant as it provides an indication of how likely a given vehicle is to be to be involved in a crash.

Police-Reportable vs. Total Number of Accidents

One of the first steps in utilizing any accident data base is to recognize that not all vehicle accidents that occur are reported to the police. This underreporting is due to several reasons, as indicated below.

In part, the lack of reporting is due to damage and injury thresholds that must be exceeded before an accident becomes police-reportable, and therefore suitable for potential inclusion in the GES data. In addition, some accidents occur to non-licensed or non-insured drivers and, while technically reportable, are often still not reported by the parties involved. Table 1 represents estimates listed by Miller et al. which indicate projections of the number of accidents that may not be included in data bases of police-reportable accidents. [9] This estimate indicates that there may actually have been 2.5 times as many accidents in total, than were reported. The use of this type of global adjustment factor leads to a crash rate of 4375 (2.5 x 1750) crashes per billion veh-km (7040 (2.5 x 2816) crashes per billion veh-mi).

Table 1. Estimated reporting of accidents to police and insurers. [9]

Percentage Of Accidents	Reported To Police	Not Reported To Police
Reported To Insurers	43 %	29 %
Not Reported To Insurers	4.5 %	23.5 %

Potentially, some scale factor could be included post-hoc in the analysis of this paper to adjust the number of police-reportable accidents to the total nurnber of potential accidents that may have occurred. However, as this scale factor is likely to be non-uniform across different accident types and severity, such scaling was not performed. The remainder of this report will therefore concentrate primarily on police-reportable accidents, as reported. This source is utilized almost exclusively in other accident data bases, which in turn are the source of most analyses published in the literature.

The above noted difference between the "total number of accidents" and the "number of accidents that are reported to the police" should, however, be duly considered in any analysis of the accident experience of TravTek vehicles. Specifically, the damage inspection of rental/lease vehicles returned to AVIS resulted in a level of accident reporting for this study that approached the true number of accidents. This number is higher than the subset of such accidents that would otherwise be reported to the police. It would appear that only the latter number would be comparable to any national statistics or data extracted from the literature.

Types of Accidents: Level of Damage and Number of Vehicles Involved

Not all accidents are created equal, and the rates for the most common classifications of accident types are provided in table 2 from the GES data base. (7)

Some accident data bases and accident analyses published in the literature only focus on small subsets of these accidents, while others consider almost the entire range of accident types. Furthermore, when within a fixed number of accidents the distribution between the various categories changes significantly, the associated economic costs would also change accordingly.

It should also be noted that while multi-vehicle accidents out number single vehicle accidents at a rate of 3 to 1 during the afternoon rush hours, after midnight almost the reverse is true. The predominance of single vehicle accidents during low traffic flow conditions and the predominance of multi-vehicle accidents during high traffic flow conditions has lead many researchers to refer to a U shaped relationship between accident rates and traffic volume (as traffic volume and time of day are highly correlated). This observation, and the implications for this study will be discussed in greater detail later, as the occurrence of high accident rates at low and high volumes, yet lower accident rates for moderate traffic volumes, significantly complicates any analysis of volume dependent safety effects.

At present, it can be noted that "per crash" the amount of property damage and minor injury is very similar for both single and multi-vehicle accidents. However, in terms of severe or fatal injuries, single vehicle accidents are nearly 75 percent more fatal per crash than multiple vehicle crashes. When this rate per crash is further converted into a rate per vehicle involvement, the involvement of a driver in a single vehicle accident can be shown to be at least 3 times more likely to lead to a severe or fatal injury.

The above discussion indicates that routes with similar crash rates, but with different types of accidents (single vs. multiple), will lead in the first instance to different vehicle involvements. Furthermore, even for similar vehicle involvement rates, the single vehicle crashes are much more prone to involve severe or fatal accidents. A routing analysis which exclusively focuses on accident rates would therefore result in different findings than one which deals with severe or fatal accidents.

Table 2. Accident classification by crash type and severity. (7)

Type of Accident:	Property Damage Only	Minor or Moderate Injury	Severe or Fatal Injury	Total Number of Crashes	Severe or Fatal Injuries per Crash	Severe or Fatal Injury per Vehicle Involvement
Single Vehicle	1,252,000	507,000	163,000	1,992,000 (33 %)	0.081	0.081
Multi-Vehicle	2,821,000	1,173,000	193,000	4,188,000 (67%)	0.046	0.022
TOTAL:	4,073,000 (66%)	1,681,000 (28 %)	357,000 (6%)	6,110,000		

Pyramid of Crash Risk

The above data lead to a pyramid of risk rate, which can be best summarized as table 3. It can be noted that the actual fatalities only represent about one tenth of the number of crashes which were classified by the GES data base as involving fatal or severe injury. Furthermore, as there is on average more than one fatality per fatal accident, the fatal accident rate is also somewhat smaller and is therefore provided as a separate indicator.

The purpose of table 3 is two fold. First, it permits an approximate means of converting safety data and findings from different sources, as many studies utilize different subsets of the total number of accidents. Some caution should of course be utilized in such conversions, as the conversion rates are somewhat accident type dependent. The second purpose of table 3 is to support the objectives of some of the TravTek-specific safety studies (for example the Camera Car Study) where less severe but more frequently occurring safety-related events were analyzed as surrogates for the more serious events, which could not be observed in the TravTek experiment in sufficient numbers.

It should further be noted that, variations exist among different sources in terms of what is considered a fatality. The difference is primarily a function of the time period within which an individual must die in order to be considered to have died due to causes associated with the crash of interest. The subjective nature of what is considered a minor, moderate vs. severe injury also provides for some inconsistencies between different data sources. A further distinction is often made between total fatalities, as opposed to occupant and non-occupant fatalities. The latter non-occupant fatalities may include pedestrians, pedacyclists and any other person not in a vehicle at the time of accident.

Vehicle Type of Effects

The final distinction to be made at this time is between different vehicle types, such as passenger cars, trucks, etc. The accident involvement rate of different vehicle types is provided in table 4.

Table 4 shows similar accident rates between passenger cars and light truck/utility vehicles indicating that nearly 93 percent of all vehicle-miles are traveled by a group of vehicles which have, on average, very similar crash rates. This similarity indicates that the traffic stream is dominated by a relatively homogenous type of vehicle which has a relatively constant accident rate profile. A by-product of this dominance of vehicles, with accident rates similar to passenger cars, is the fact that the accident rates for all vehicle types combined is still very similar to the accident rate for strictly passenger cars.

Table 3. Harmful event probabilities per vehicle involvement/ fatality. [7]

Event	Annual Frequency	Rate / Bill. Veh-Mi	Normalization Type 1	Normalization Type 2
Fatal Accidents	36,370	16.7	0.0034	0.87
Fatality	41,462	19.1	0.0039	1.00
Fatal or Severe Injury	357,000	164	0.034	8.6
Moderate or Minor Injury	1,681,000	774	0.15	40.5
Property Damage Only	4,073,000	1876	0.38	98.2
Crash Occurrence	6,110,000	2815	0.57	147
Vehicle Involvement	10,619,000	4893	1.00	256

1 mi=1.61 km

However, it can also be noted that large trucks, which are often perceived as being a safety hazard, are shown to experience a crash involvement rate which is less than 50 percent of the passenger car rate. The potential, that the presence of trucks on a highway facility may contribute to the occurrence of accidents around them (in which they are not actually involved) is of course not reflected in this cross-tabulation.

Table 4. Involvement rates in crashes for different vehicle types. [7]

	Number Involved in Crashes	Billions of Veh-Mi Traveled	Vehicle Involvement Rate per Billion Veh-Mi	Normalization Relative to Passenger Cars
Passenger Car	7,710,000 (72.6 %)	1.532 (70.7 %)	5030	1.00
Light Truck / Utility Vehicle:	2,475,000 (23.3 %)	0.473 (21.8 %)	5230	1.04
Large Truck:	330,000 (3.1%)	0.150 (6.9 %)	2190	0.46
Motor Cycle:	104,000 (0.9%)	0.009 (0.4 %)	11340	2.25
TOTAL:	10,619,000	2.165	4902	0.97

1 mi=1.61 km

Time Dependency of Data (Year to Year)

A final factor, that should be discussed, is the time dependency of safety data as shown in table 5. In other words, the historical trends in accident data during the past decade.

It can be noted from table 5 that during the past decade, the total number of annual accidents has been decreasing at a-moderate rate (-5.4 percent), while the amount of travel has continued to increase steadily (+2.4 percent). The net result of these two rates is that the accident rate per unit of exposure has decreased at a more noticeable rate of -6.6 percent.

One response to these trends would be to apply a similar scale factor to any accident rate from the literature when either comparing sources of different age, or when comparing aged safety to TravTek accident data from 1992/93. An alternative response would be to attribute a causal relationship to the increase in traffic volume and the decrease in accident rate per unit of exposure. Such an effect, while plausible, would the ignore any differences in reporting standards or vehicle/traffic safety that may also have contributed to these annual reductions.

Table 5. Historic trends in safety and traffic statistics.

Measure	1980	1988	1989	1990	1991	Annual Rate of Change
Number of Crashes (in 1000's)		6,887	6,645	6,462	6,110	- 5.4 %
Daily Veh-Mi per Mile	1082	1430	1489	1516		+ 1.8 %
Billion Veh-Mi Traveled	1.527	2.026	2.098	2.148		+ 2.4 %
Crash Rate per 10^9 veh-mi		3390	3060	3010	2810	- 6.6 %
Number of Fatalities	51,091	47,093	45,555	44,529		- 2.2 %
Urban Interstate Congestion	52 %	67 %		69 %		+ 1.5 %
Number of Miles of Highway	3,857	3,871	3,877	3,880		+0.08 %

1 mi=1:61 km

A Note on Reliability of Accident Rate Statistics as a Function of Exposure

Prior to proceeding with the interpretation of the above statistics on accident rates and vehicle involvements, it is important to qualify any numbers by the associated levels of confidence in these numbers. Specifically, it will be shown that the level of confidence in accident rates is highly dependent upon both the mean rate and the amount of exposure associated with each of these mean rates. This relationship is illustrated in figures 6 and 7.

Figure 6 indicates how the standard deviation of the mean accident rate changes as a function of exposure for a reference accident rate of 4.03 accidents per million veh-km (2.5 accidents per mvm). It can be noted that approximately 644,000 veh-km (400,000 veh-mi) of exposure data need to be collected before the standard deviation becomes less than the mean, and more than 2.42 million veh-km (1.5 mvm) of data need to be collected before the mean rate is equal to or greater than 2 times the standard deviation (a measure which under the assumption of normality would represent the lower bound of the 95 percent confidence limits).

The estimation of the standard deviation is conditional on the accident occurrence process being Poisson. This assumption is appropriate, as the Poisson distribution considers the occurrence of accidents to be independent in time of a previous occurrence. On the other hand, the use of symmetric confidence limits on the mean requires the probability distribution to be approximated reasonably by means of a normal distribution. This approximation is not valid for small numbers of veh-miles. The consequence of approximating the Poisson distribution by the normal distribution would be to under estimate both the magnitude of the 2.5th and the 97.5th percentile. As a result, with the real Poisson distribution, it would be slightly easier to distinguish accident rates which were lower than the base accident rate. However, it would also make it more difficult to distinguish accident rates which were higher than the base accident rate.

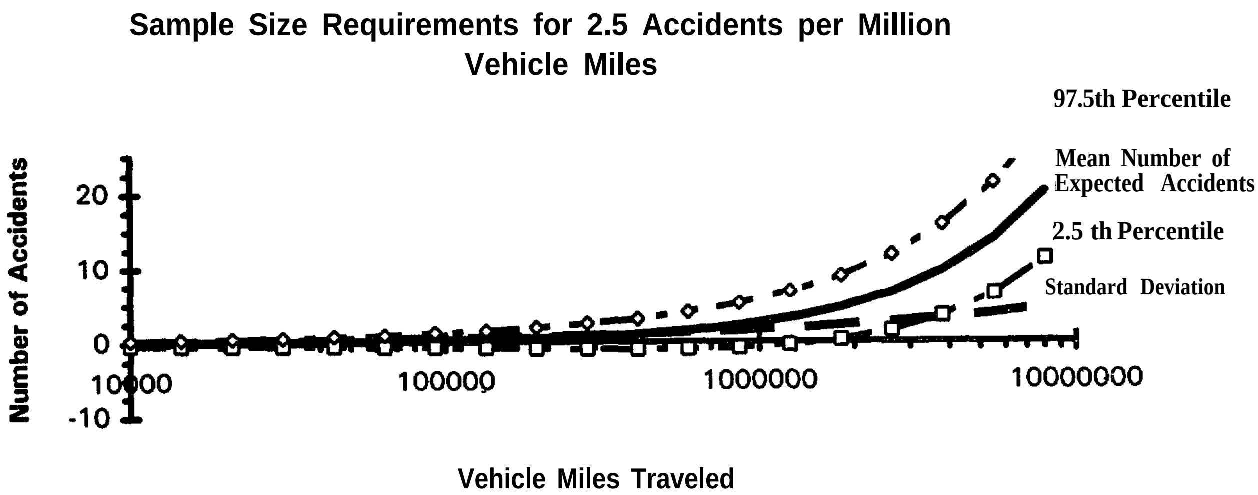


Figure 6. Confidence limits in accident rates as a function of exposure.

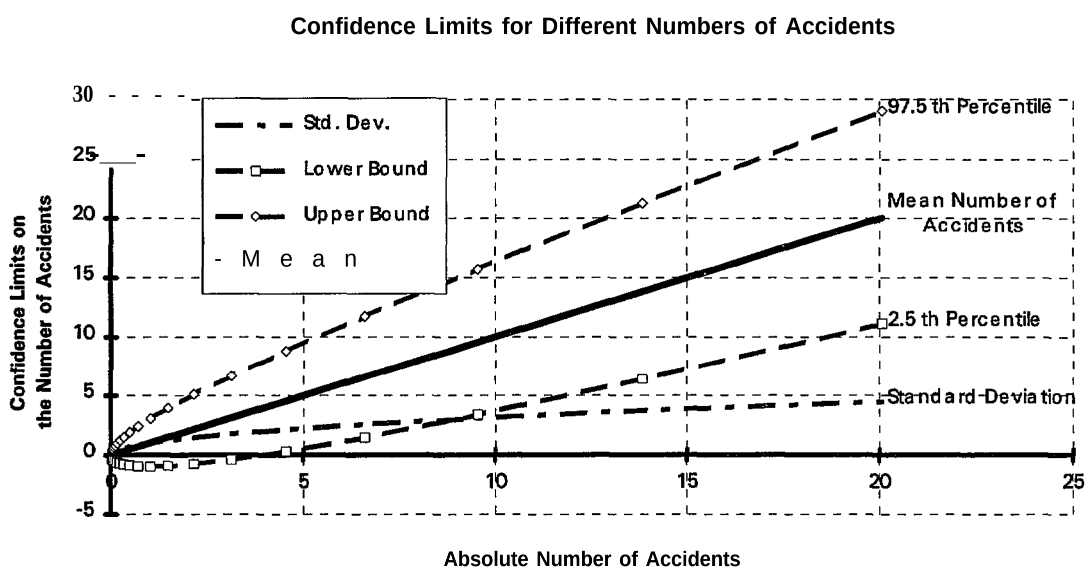


Figure 7. Variability in accident frequencies as a function of the number of accidents observed.

FACILITY TYPE OF EFFECTS OF ACCIDENT RISK

The most comprehensive source of accident experience by facility type is published by the FHWA in its annual report of fatal accidents for various types of rural and urban roads. [8] This section of the report examines these statistics with the intent of establishing statistical evidence which would relate road facility type to level of risk exposure.

The significance of this analysis to a TravTek type of system is two-fold. First, TravTek has a feature in its routing algorithm which results in the selection of higher road type of facilities over lower class facilities. The analysis in this section will attempt to examine the safety impact of such a bias. Second, there is a high correlation between facility type and the traffic volume that is carried on each facility. Consequently, an analysis of facility type needs to precede any traffic volume effects analysis, as there is otherwise a risk of assigning any changes in safety level to the wrong factor.

Basic Highway Mileage and Travel Statistics Provided

Table 6 provides a summary of the data that are provided by the FHWA. (8) The number of categories have been grouped from the original source document to permit a direct comparison of rural vs. urban facilities. Furthermore, the distinction between facilities that are part of the Federal-aid vs. those which are not has also been removed.

It can be noted from table 6 that approximately 80 percent of the length of all roads is rural, of which rural local roads represent 55 percent of the total. In comparison, only 20 percent of all roads are urban, with urban Interstates and other principal roads representing only 0.3 percent and 1.54 percent of the total. In contrast, of the annual vehicle-miles that are traveled, only 40 percent occur on rural roads and nearly 60 percent of all travel occurs on urban roads. Furthermore, 13 percent of all travel occurs on urban Interstate, while an additional 22 percent of all travel occurs on other urban principal roads.

The reason for this shift in percentages derives from the much greater degree of utilization of the urban routes, as is indicated in their respective Annual Average Daily Traffic (AADT). For example, while rural local roads carry an average of only 125 vehicles per day, urban Interstates average 66,000 veh/day. On average, urban roads carry 6 times as much traffic per km as rural roads (4600 vs. 760). It should also be noted here that the busiest North American Freeways carry about 300,000 veh/day, while the busiest hour during the day represents typically about 10 percent of the AADT.

From the point of view of a TravTek type of system, observations can be made. One can note that as part of a nation-wide deployment, 80 percent of the road network that needs to be coded within an ATIS data base will be in a rural environment. However, 60 percent of the use of the ATIS system would be expected to be in an urban environment. These inferences, assume that urban and rural road networks will be covered at an equal level of detail, and that the use of an ATIS type system by road type is proportional to the mileage driven on each.

Table 6. Basic accident and highway statistics for 1990.[8]

Road Type (Category)	Road Locale	Road Mileage	Normalized	Annual Veh-Mi	Normalized	AADT	Normalized
		(mi)	(%)	(millions)	(%)	veh/day	(fraction of base)
Interstate	Rural	33547	0.86	200573	9.34	16380	10.80
	Urban	11527	0.30	278404	12.96	66171	43.64
Principal Arterials	Rural	83802	2.16	175382	8.17	5734	3.78
	Urban	59657	1.54	463118	21.57	21269	14.03
Minor Arterials	Rural	144735	3.73	155844	7.26	2950	1.95
	Urban	74656	1.92	235036	10.94	8625	5.69
Collectors	Rural	730277	18.82	241764	11.26	907	0.60
	Urban	78248	2.02	103756	4.83	3633	2.40
Locals	Rural	2130427	54.91	96846	4.51	125	0.08
	Urban	533275	13.74	196778	9.16	1011	0.67
Combined	Rural	3122788	80.48	870409	40.53	764	0.50
	Urban	757363	19.52	1277092	59.47	4620	3.05
	Total	3880151	100.00	2147501	100.00	1516	1.0

1 mi=1.61 km

Table 7. Fatal injury accident data per 1000 mi and 1 billion veh-mi.[8]

Road Type (Category)	Road Locale	Number of Fatal Accidents	Normalized	Fatal Accidents per 1000 mi		Normalized	Fatal Accidents per billion veh-mi		Normalized
		(#)	(%)	(mean)	(Std. Dev.)	(fraction)	(mean)	(Std. Dev.)	(fraction of base)
Interstate	Rural	2258	5.7	67.31	1.42	6.57	11.26	0.24	0.61
	Urban	1965	4.9	170.47	3.85	16.63	7.06	0.16	0.38
Principal Arterials	Rural	4018	10.1	47.95	0.76	4.68	22.91	0.36	1.24
	Urban	7134	17.9	119.58	1.42	11.66	15.40	0.18	0.83
Minor Arterials	Rural	4379	11.0	30.26	0.46	2.95	28.10	0.42	1.52
	Urban	3734	9.4	50.02	0.82	4.88	15.89	0.26	0.86
Collectors	Rural	7786	19.6	10.66	0.12	1.04	32.20	0.36	1.74
	Urban	1309	3.3	16.73	0.46	1.63	12.62	0.35	0.68
Locals	Rural	3956	9.9	1.86	0.03	0.18	40.85	0.65	2.21
	Urban	3240	8.1	6.08	0.11	0.59	16.47	0.29	0.89
Combined	Rural	22397	56.3	7.17	0.05	0.70	25.73	0.17	1.39
	Urban	17382	43.7	22.95	0.17	2.24	13.61	0.10	0.73
	Total	39779	100.0	10.25	0.05	1.00	18.52	0.09	1.00

1 mi=1.61 km

Basic Accident statistics Provided

The above FHWA document also provides the number of fatal injury accidents for each facility type, as indicated in table 7.[8] It can be noted that rural roads still result in 56 percent of all fatal accidents, and that rural collectors provide nearly 20 percent of all such accidents. In contrast, both urban and rural Interstate provide just over 10 percent of all accidents, with urban Interstates resulting in less than 5 percent of all accidents.

The common perception that accidents are rather frequent occurrences on urban Interstates is substantiated in the tabulation of accident rates per km of highway facility. In this case, the national average of 10 fatal accidents per 1610 km (1000 mi) of highway is clearly seen to be much higher on urban Interstates (170 fatal accidents per 1610 km (1000 mi)). Furthermore, it can be noted that, in general, more than 3 times as many accidents occur per km on urban roads than on rural roads (22.95 vs. 7.17 per fatal accidents per 1610 km (1000 mi)). It can also be noted that these differences are highly statistically significant in view of the derived standard deviations. These standard deviations were obtained by considering that the number accidents per year follows a Poisson distribution, allowing the variance of the observed frequency to be estimated as the mean frequency.

The number of accidents per km is a statistic that is of greatest interest to highway operators, as it provides them an assessment of where accidents occur most frequently. From a user point of view, this rate per km of highway also reflects the fact that drivers will pass by more accident sites per km on urban Interstates than on any other facility, and that on urban Interstates non-recurring congestion is also most prevalent. However, in terms of an individual driver's personal involvement in an accident, the accident risk per vehicle-km (rather than per km of roadway) is much more important, as is illustrated next.

The final columns of table 7 indicate that across the United States 18.52 fatal accident occur per billion vehicle miles that are driven. In this case, urban accident rates are only about 50 percent of the rural rates per veh-km (13.61 vs. 25.73). This differential trend is maintained for virtually all facility types. Of special interest is the fact that urban Interstate fatal accident rates are, on a per veh-km basis, experiencing only 38 percent of the accident rate that is observed nation wide. Other principal urban roads and arterials are, in contrast, experiencing fatal accident rates which are nearly twice as high as the urban Interstate rate.

Conversion of Fatal Accidents to Total Reportable Accidents

To convert the number of fatal accidents to a total number of reportable accidents, two separate scale factors were applied. The first factor, which was facility independent, scaled the number of fatal accidents to a number of serious and fatal accidents. [7,8] This factor could be found from table 3 as 357,000/36,370. In addition, a second factor was applied, which converted the number of severe or fatal accidents in to a total number of accidents. As can be noted in Column 4 of table 8, that for roads which have a speed limit of 97 km/h (60 mi/h) about 12 percent of all accidents involve serious or fatal injuries. In contrast, at a speed limit of 32 km/h (20 mi/h), less than 5 percent of all accidents involved serious or fatal injuries. By means of assigning typical speed limits to each of the highway types, as indicated in Table 8, a modified accident rate was developed.

This modified accident rate for each highway type, when multiplied by the exposure on each highway facility type, resulted in an estimated number of total accidents. [7] This number was subsequently scale by 95 percent to match the actual accident total. The need for such scaling arises from the use of a first scale factor which was not facility dependent, and from the errors associated in assigning "typical" speed limits to each facility type.

One can note that the final crash rates (4580 vehicles per billion veh-km (2845 vehicles per billion veh-mi) and vehicle involvement rates that are reported in the final columns of table 8 are consistent (for all facility types combined) to the rates listed earlier. No objective source was found to scale the vehicle involvement differently for differently for different facility types, even though the mix of single to multiple vehicle accidents is likely to differ somewhat.

Table 8. Total accidents and vehicle involvement by facility type.

Road Type (Category)	Road Locale	Nominal Speed Limit	Severe or Fatal Accidents per Crash	Estimated Total Reportable Accidents	Total Accidents per Unit of Exposure		Normalized	Total vehicle involvement	
		(mi/h)	(fraction)	(#)	(#/billion veh-mi)	(#/billion veh-km)	(fraction of base)	(#/billion veh-mi)	(#/billion veh-km)
Interstate	Rural	60	0.1238	169679	846	526	0.30	1455	904
	Urban	60	0.1238	147661	530	330	0.19	912	567
Principal Arterials	Rural	50	0.0827	451991	2577	1602	0.91	4432	2755
	Urban	50	0.0827	802514	1733	1077	0.61	2980	1852
Minor Arterials	Rural	40	0.0598	681238	4371	2717	1.54	7518	4672
	Urban	40	0.0598	580896	2472	1536	0.87	4250	2642
Collectors	Rural	30	0.0474	1528133	6321	3928	2.22	10870	6756
	Urban	30	0.0474	256913	2476	1539	0.87	4258	2647
Locals	Rural	20	0.0449	819663	8464	5260	2.97	14555	9046
	Urban	20	0.0449	671311	3412	2120	1.20	5867	3646
Combined	Rural			3650704	4194	2607	1.47	7213	4483
	Urban			2459296	1926	1197	0.68	3312	2058
	Total			6110000	2845	1768	1.00	4893	3041

1 mi=1.61 km

Discussion of National Accident Rates by Facility Type

The final numbers indicate that, in terms of total reportable number of accidents per billion vehicle km, urban Interstates are approximately 3 times safer than major urban arterials, while they are more than 4 times as safe as urban minor arterials and collectors. Finally, urban Interstates are up to 6 times safer than urban local roads. It can also be noted that urban Interstates and other major roads are about 1.5 times safer than their rural counterparts, while for collectors and locals, the safety margin increases to approximately 2.5 times the urban rate.

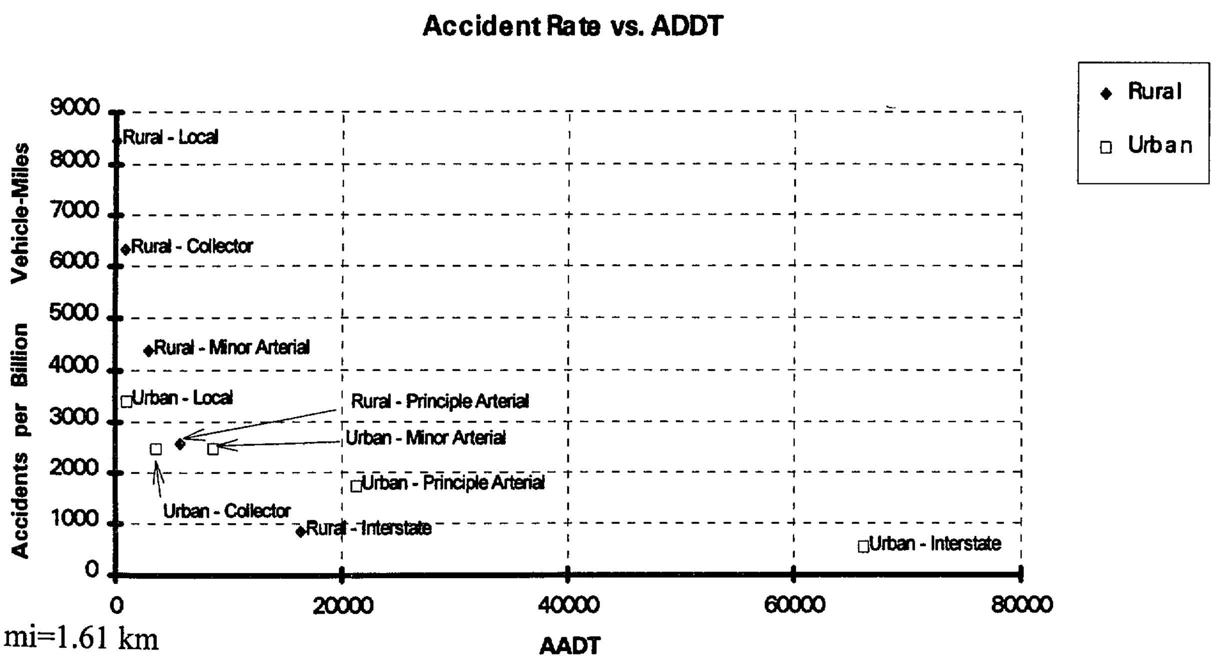
From a TravTek point of view, there are three significant implications that can be derived from the above analysis. First, the differences between the urban vs. rural accident rates indicated that the use of a national average across both travel environments potentially overestimates the base accident rate for TravTek system users in Orlando. The reason for this is that the urban average is only 68 percent of the national average (3100 accidents per billion veh-km vs. 4580 (1926 accidents per billion veh-mi vs. 2845)). This first note is based on the assumption that most of the travel by users of the TravTek system was on urban roads.

The second implication is that the hierarchical structure of the TravTek route calculation algorithm (which favors higher facility roads over lower classes), has a built in safety benefit. Specifically, the preference of the algorithm of freeways over arterials/collectors/locals makes the algorithm automatically select routes which are 4 to 6 times safer.

The third implication is closely associated with the second one. Specifically, during any diversions the reverse argument can be utilized to illustrate that any diversion of traffic from Interstates onto arterials will result in a corresponding increase in accident risk. This risk effect would be present even if the two routes are equal in length. The analysis does ignore, however, the fact that the accident rate on a congested freeway may be higher than on either an uncongested or a congested arterial. However, such an inference requires an analysis beyond the one that was carried out in thus far.

Further Analysis of Accident Rates by Facility Type

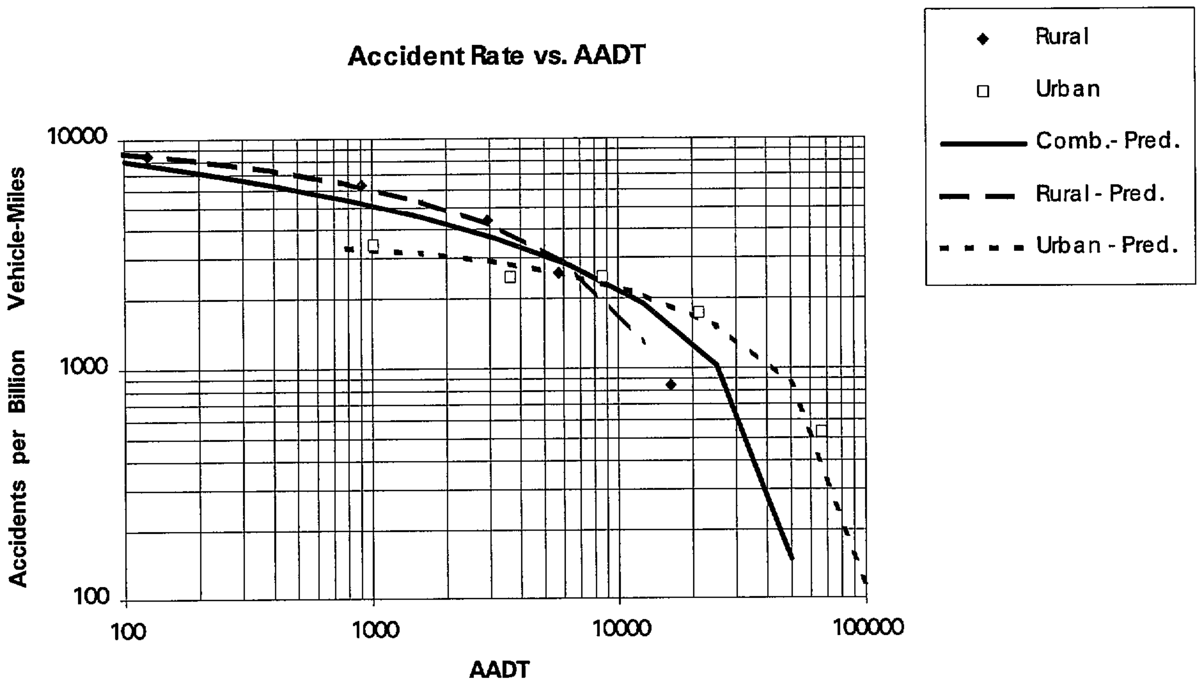
Figure 8 presents the data using simple linear axes and reveals that, except for the urban Interstate values, much of the data are clustered below an AADT of 25,000 veh/h. Furthermore, the wide range of accident rates for this narrow range of low traffic volumes makes it rather difficult to discern any relationships between them. Consequently, the following analyses are performed using logarithmic transformations of the data.



1 mi=1.61 km

Figure 8. Accident rate vs. AADT—Linear and linear axes—Raw data.

The dual logarithmic axes of figure 9 illustrate that the accident rates corresponding to the data of table 8 follow a downward trend as a function of AADT for both rural and urban roads. Furthermore, it can be noted that at lower volumes the accident rate on rural roads is higher, while at higher volumes the rate is lower. In order to capture this decreasing trend in accident rates, as a function of AADT (for both rural and urban roads combined), a linear regression was fit. Its properties are listed in table 9 as equation 1, while the actual shape of the curve is provided in figure 9. Separate regressions were also performed for the rural and urban data, and these results are illustrated as equations 2a and b. Unlike the regression for the combined data, for the separate urban and rural data a quadratic model was found to be superior for each data set, as shown in figure 9.

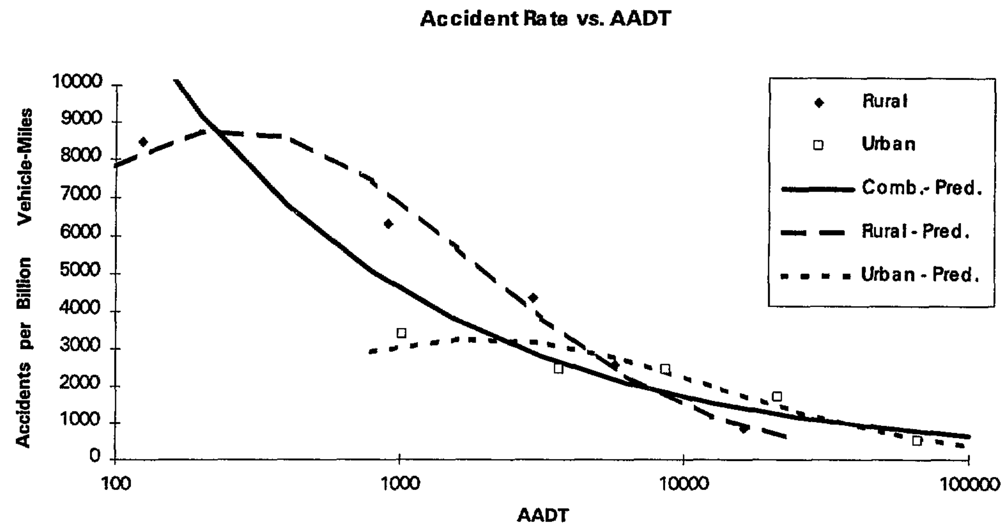


1 mi=1.61 km

Figure 9. Accident rate vs. AADT—Log and log axes—$Y = a X^{b}$ relationships.

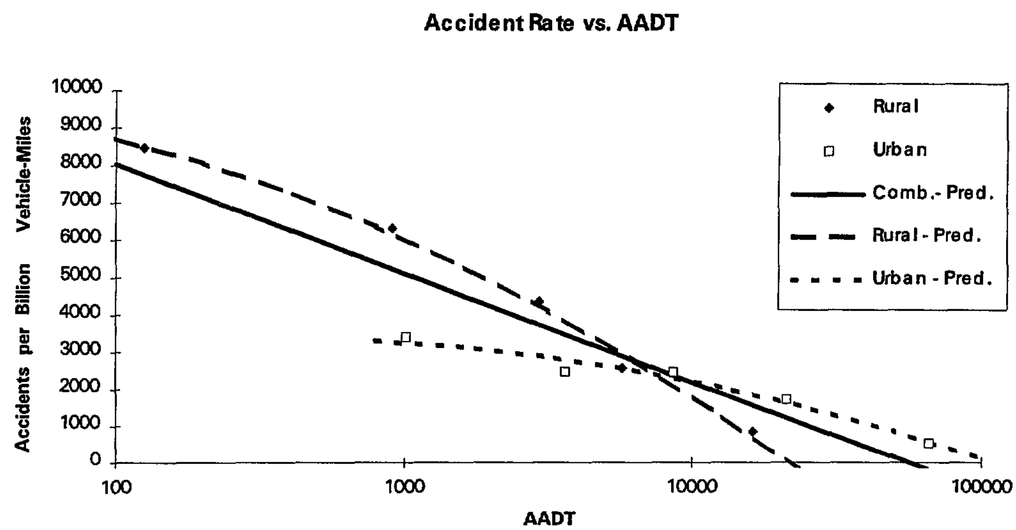
Figure 10 provides a plot of traffic volume versus accident rate in which only the traffic volume rate is made logarithmic. Equations 1, 2a and 2b are plotted on this graph. In absolute terms, the high R-Squared values in the log transformations were clearly somewhat misleading. However, it should be noted that the logarithmic transformation has the beneficial attribute of minimizing relative estimation errors. Specifically, a simple linear variable of accident rate considers an error of 1 percent, in an accident rate of 10,000 accidents per unit of exposure, equivalent to a 10 percent error, in an accident rate of 1,000 accidents per unit of exposure. The log transformation of the accident rate makes a 10 percent error be of an equivalent weight for any value of the actual accident rate. This effect can be noticed from the very good absolute fit of accident rates for the low accident rates encountered on urban Interstates.

Figure 11 illustrates a plot of the above data using a logarithmic scale for AADT and a linear scale for accident rates. Equations 3, 4a and 4b illustrate the relationships that were fit through the data in this format. Specifically, equation 3 illustrates that a linear curve can capture much of the variability that is encountered (R-square=0.886). However, such a plot has the undesirable effect of creating a negative accident rate for traffic volumes below 100,000 veh/day. Similarly, equations 4a and 4b illustrate that there exist good fits to the separate rural and urban data for non-linear curves. Unfortunately, each still has the undesirable attribute of predicting negative accident rates for moderate to high traffic volumes. Finally, figure 12 illustrates the relative errors of the relationships that were fit in figure 11 to minimize absolute errors.



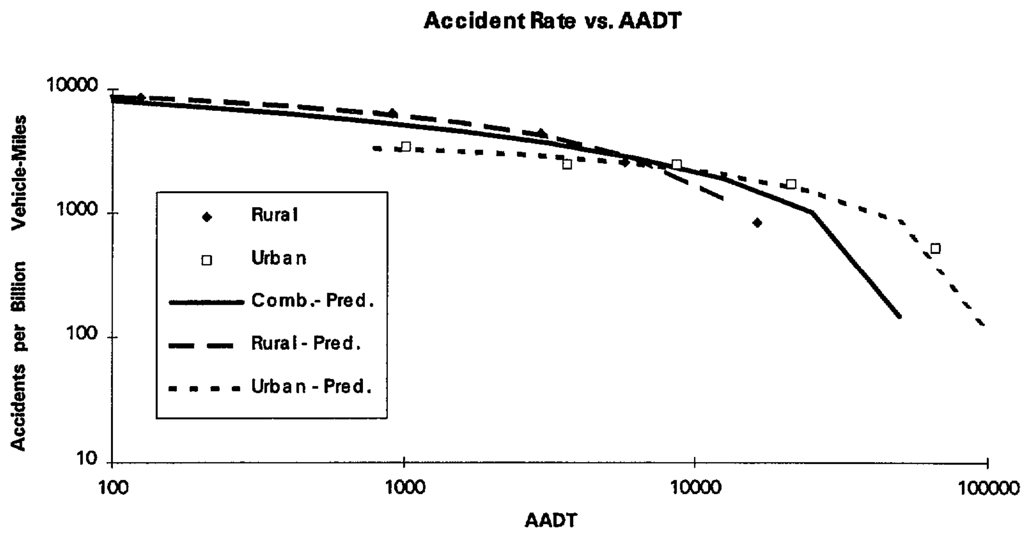
1 mi=1.61 km

Figure 10. Accident rate vs. AADT—Linear and log axes—$Y = a X^b$ relationships.



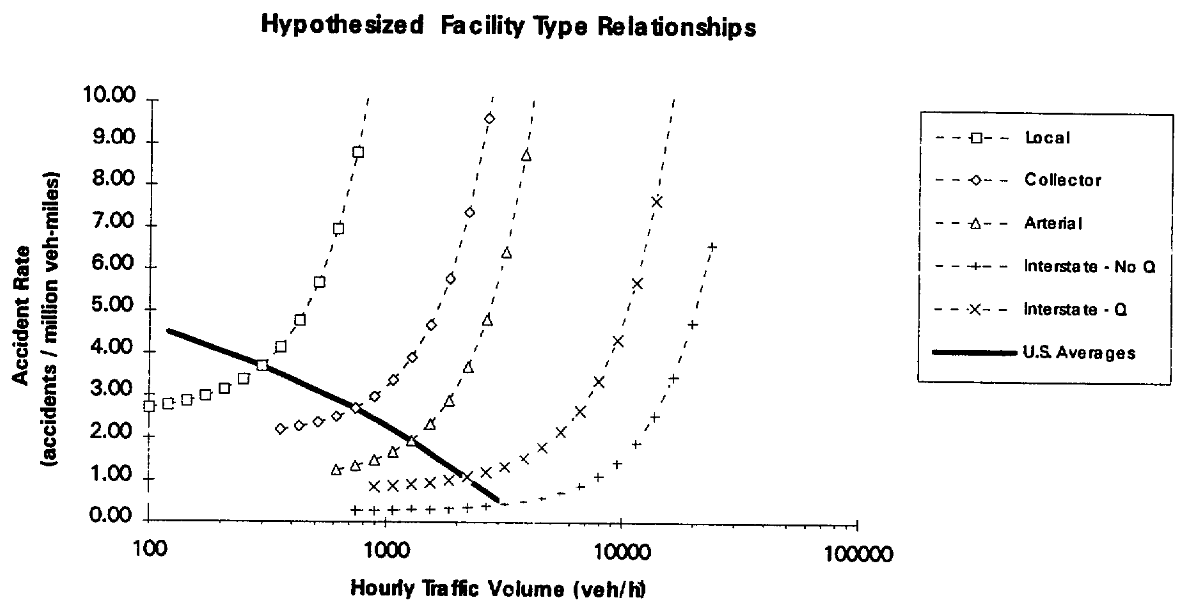
1 mi=1.61 km

Figure 11. Accident rate vs. AADT—Linear and log axes—$Y = a + b \log X$ relationships.



1 mi=1.61 km

Figure 12. Accident rate vs. AADT—Log and log axes—Y = a + log X relationships.



1 mi=1.61 km

Figure 13. Accident rate vs. AADT—Linear and log axes—Hypothesized relationship.

Table 9. Regression equations for accident rates as a function of AADT.

Equation Number	Independent Variable	Equation	R^2	F-Ration Probability	Comments
1	Combined Accidents per Billion Veh-Miles	Acc=4.95 – 0.29 * AADT	0.841	0.000185	-non-linear effects were not found to be significant
2a	Rural Accidents	Log(Acc)=2.168+1.475* Log (AADT)-0.306* Log(AADT)^2	0.991	0.00876	-curvature in log-log plot was significant
2b	Urban Accidents	Log(Acc)=0.137 Log (AADT)-0.325* Log (ADDT)^2	0.955	0.03055	-intercept was not found to be significant
3	Combined Accidents per Billion Veh-Miles	Acc=13879-2921 * Log (AADT)	0.975	0.00009	-non-linear effects were not found to be significant
4a	Rural Accidents	Acc=11199-585.6*Log (AADT)^2	0.993	0.00026	-linear term was significant by itself but became insignificant when quadratic term was added.
4b	Urban Accidents	Acc=0+2687*Log(AADT) -532.7*Log(AADT)^2	0.964	0.02442	-Intercept became insignificant following introduction on quadratic term

1 mi= 1.61 km

Discussion of Regression Analyses

Both the linear relationships for the combined data and the quadratic relationships for the separated data suggest that there may be a highly significant decrease in accident rates as the AADT of a highway increases. However, such an apparent trend is likely very misleading due to the very high correlation between facility type and accident rate. Specifically, it is likely that the apparent decrease in accident rate for higher traffic volumes is simply due to the fact that higher volumes are simply observed on facilities that are intrinsically safer. Under this assumption, the set of curves that was illustrated in figures 9 to 12 would simply represent a series of points. Each series of points would be from a different curve, where each individual curve has a positive slope with respect to traffic volume. This is illustrated using an idealized example in figure 13. The potential presence of this trend is explored in the following section of this paper.

The above regression analyses do provide, however, useful equations for predicting accident rates for planning purposes. Specifically, if it is assumed that as the AADT on a given highway is increased, the facility will be upgraded in class to match, the equations indicate that accident rates will decrease. Furthermore, while rural accident rates for each highway class were higher than the corresponding urban rates, the regressions indicate that much of that difference is explained purely by the fact that the urban roads carry more traffic. Specifically, if one utilizes the linear regression of figure 9 for the combined facilities, one can note that the rural accident rates are fully consistent with the traffic volume trends observed in the urban data.

The fact that the above analyses may lead to a potentially misleading impression, that increased traffic volumes (and therefore perhaps increased traffic congestion), leads to improved accident rates per veh-km traveled requires further analysis. Specifically, as there is a high correlation between traffic volume and facility type, there is a need to perform a traffic volume analysis for strictly data that are all collected on the same facility. Such an analysis is not possible based on nation-wide statistics, as separate accident rate and exposure data are not available for individual roads. Furthermore, the fact that facilities of the same type may experience different accident rates for different traffic volumes does not necessarily automatically imply that an increase in traffic flow on the same facility will result in the same change in accident rates. Finally, it is important to distinguish between an increase of traffic volume that occurs over several years and one that occurs during the peak periods of a given day. The latter is clearly the preferred relationship to be calibrated. However, this calibration now requires both traffic volumes and accident rates to be stratified by time of day for a long enough period. This stratification would ensure that the variance that is inherent in the low frequency events of accidents becomes less than the magnitudes of the trend that are being investigated.

TRAFFIC VOLUME EFFECTS ON A GIVEN FACILITY

The analysis of the impact of traffic effects on a given facility can be performed using a number of different approaches, each with their own limitations, as discussed next.

The first approach is to analyze a range of highways across the United States and to compare the accident rates for highways which carry a lot of traffic to those which do not. This type of analysis is complicated, however, as different highway types not only carry different amounts of traffic, but also have different geometric designs. When one group of highways is compared to another, it is therefore unclear if the difference is due to the change in traffic volume or due to the change in geometric design standards.

The second approach is to compare on an annual basis highways with similar geometric standards and analyze some which are busy, and some which are not so busy, based on their respective AADT values. This type of analysis normalizes with respect to facility type, but as shown later, there are very different factors at play during day-time versus night-time conditions, which modify the accident rate to a greater extent than the presence or absence of traffic congestion. An analysis of this approach is presented next based on data from the literature.

The final analysis is to consider the impact on the same facility of the presence or lack of traffic congestion during day-time conditions only. This requires accident and traffic flow data to be present for the same facility in a manner which permits the categorization of accidents into these classes, and requires there to exist sufficient numbers of observations in each category. This approach will be illustrated using data for I-4 in Orlando.

Literature Findings on the Impact of Congestion on Accident Rates

The peak hour accident rate in relation to the level of congestion was examined by Hall and de Hurtado for several hundred signalized intersections in Albuquerque, New Mexico.[10] The equations developed for estimating the accident rate as a function of volume to capacity ratios (V/C) had relatively high standard errors and thus could not easily be used for predictive purposes at individual sites. However, average peak hour accident rates for 326 intersections studies were presented, and the relationship for different v/c ratios and accident rates was used in the TravTek study to represent the effect of congestion on accident risk. The analysis showed that accident rates increased by a factor of 1.25 for congested arterials.

In terms of freeways, a study was performed in California to examine the impact of traffic congestion on accident rates. [11] This effect which was found to vary depending upon the prevailing geometric conditions was found to yield a 3:1 change in accident rate between congested and non-congested freeway conditions. In other words, when traffic congestion was present, the accident rate on the freeway was typically 3 times higher than when no queues were present. The fact that the impact on accident rates was dependent upon the highway's geometry was the basis for analyzing accident data specifically for I-4 in Orlando, as discussed next.

Analysis of I-4 Data for Orlando

In order to examine the impact on accident rates of congestion in Orlando, both accident data and traffic flow data were assembled in a consistent fashion for the entire section of I-4 within Orlando. Specifically, accident statistics were obtained from the Florida DOT, and these data were summarized by time of day and day of the week. Similarly, traffic flow data for I-4 within the Orlando area were collected and summarized by time of day and day of the week. The summary results are provided in table 10 and illustrated in figures 14 to 16.

Figure 14 illustrates the total number of annual accidents that occur on I-4 on Saturdays, Sundays and a typical Weekday as a function of the time of day. From figure 14 it can be noted that the largest number of accidents occur around 1 and 2 a.m. on Saturday and Sundays, and during the a.m. peak and p.m. peak on weekdays.

Figure 15 illustrates the corresponding traffic flows throughout the same 24-hr time period. It can be noted that the weekdays experience strong traffic flow peaks during the a.m. and p.m. commuter peaks, but that the mid-day traffic flows are approximately 70 to 80 percent of the peak flows. On weekends the flows, also expressed in terms of Million Vehicle Miles Traveled (MVMT), do not have the same a.m. and p.m. commuter peaks, but have mid-day flows which are nearly equal to the weekday mid-day flows. It can also be noted that evening flows are highest on Saturdays, and that early morning traffic flows are highest on Saturday and Sunday mornings.

Figure 16 represents the ratio of the accident frequencies in figure 14, divided by the traffic flows in figure 15. The high accident frequencies during the early a.m. hours on weekends are not proportional to the observed traffic flows. They therefore result in very high accident rates. Less obvious is the fact that on weekdays the accident rates do vary considerably, but this variation is dwarfed in comparison to the quantum jump in accident rates on Saturday and Sunday mornings. In order to be able to analyze the details of the weekday, Saturday and Sunday variations, figures 17, 18 and 19 were created, as discussed next.

It can be noted in figure 17 that the accident rate on weekdays peaks more strongly than the traffic flows. This implies that the increase in accidents during the a.m. and p.m. peaks is much greater than simply the increase in traffic flow would suggest. The most obvious conclusion from this fact is that the increase in accident rate must be due to the presence of traffic congestion. The exact magnitude of this impact will be determined later from figure 20. Figure 18 illustrates that a similar peaking in accident rates occurs during the a.m. and p.m. peaks on

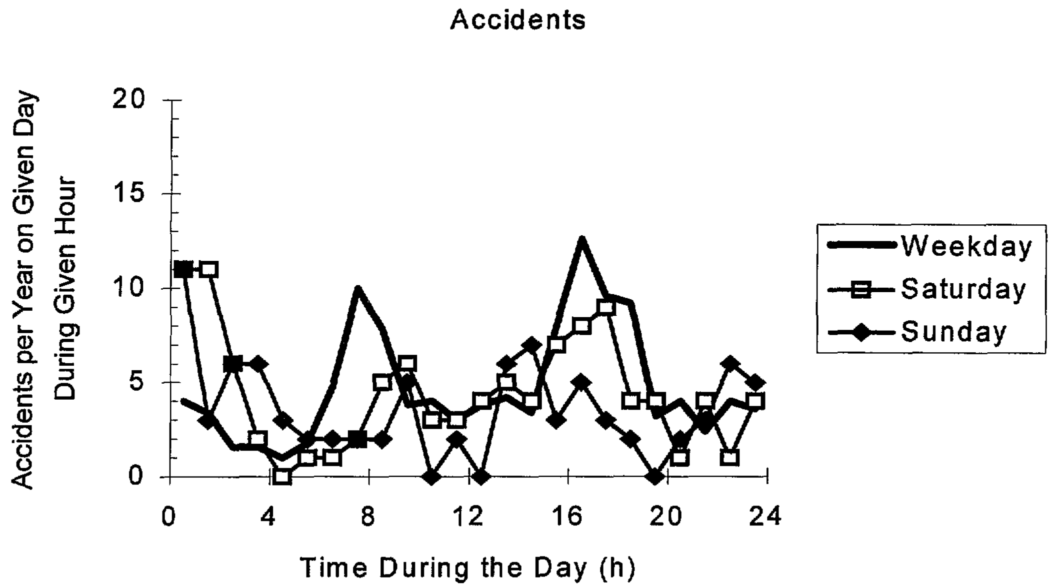
Saturdays. This effect is not anticipated, as on Saturdays there are no a.m. and p.m. peaks in the traffic flow rates. Similar surges in accident rates are also observed in figure 19 on Sundays. The effects on weekends are, however less significant as the number of observations of accidents on Saturdays (1/7) is only 20 percent that of accidents on weekdays (5/7).

Table 10. Summary of accident rates and traffic flow rates on I-4 by day-of-week and time-of-day.

	Accident Frequency for Given Day During Given H			Millions of Veh-Mi Traveled on I-4			Accident Rate for Given Day During Given H		
	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
0.5	4	11	11	0.988	1.779	1.983	4.048	6.182	5.548
1.5	3.4	11	3	0.600	1.172	1.359	5.665	9.386	2.208
2.5	1.6	6	6	0.493	0.957	1.035	3.243	6.273	5.797
3.5	1.6	2	6	0.413	0.583	0.600	3.874	3.432	9.997
4.5	1	0	3	0.583	0.543	0.479	1.716	0.000	6.268
5.5	1.8	1	2	1.506	0.869	0.612	1.195	1.151	3.266
6.5	4.8	1	2	4.339	1.855	1.188	1.106	0.539	1.683
7.5	10	2	2	6.543	2.908	1.832	1.528	0.688	1.092
8.5	7.8	5	2	6.358	3.960	2.582	1.227	1.263	0.775
9.5	3.8	6	5	5.421	4.563	3.406	0.701	1.315	1.468
10.5	4	3	0	5.214	4.976	4.059	0.767	0.603	0.000
11.5	3	3	2	5.266	5.175	4.127	0.570	0.580	0.485
12.5	3.8	4	0	5.114	5.272	4.743	0.743	0.759	0.000
13.5	4.2	5	6	5.387	5.140	4.530	0.780	0.973	1.324
14.5	3.4	4	7	5.838	5.078	4.584	0.582	0.788	1.527
15.5	8	7	3	6.457	5.181	4.657	1.239	1.351	0.644
16.5	12.6	8	5	6.649	5.237	4.885	1.895	1.528	1.024
17.5	9.6	9	3	6.607	5.196	4.968	1.453	1.732	0.604
18.5	9.2	4	2	5.670	4.952	4.361	1.623	0.808	0.459
19.5	3.2	4	0	4.010	4.119	3.582	0.798	0.971	0.000
20.5	4	1	2	3.012	3.149	2.859	1.328	0.318	0.699
21.5	2.4	4	3	3.002	3.121	2.444	0.799	1.282	1.227
22.5	4	1	6	2.484	3.265	2.201	1.610	0.306	2.726
23.5	3.6	4	5	1.752	2.819	1.526	20.55	1.419	3.277

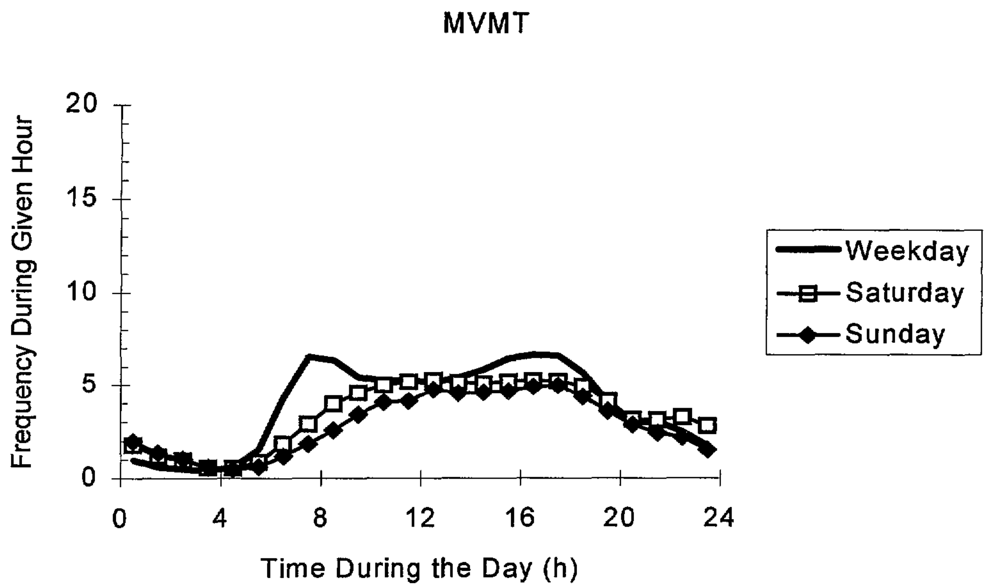
1 mi=1.61 km

A detailed comparison of accident rates for each time of the day is provided in figures 20,21 and 22. During a.m. and p.m. peaks the accident rate increases from an off-peak day time average of 0.50-0.75 accidents per MVMT to about 1.25-1.50 in morning peak and to about 1.25-2.00 in the p.m. peak. This finding could be interpreted to provide a congestion impact on accident rates of between 2-4, a value consistent with the literature findings. The reliability of the above finding is, however, reduced due to the finding of a similar increase in accident rates on Saturdays, when no a.m. or p.m. congestion usually occurs.



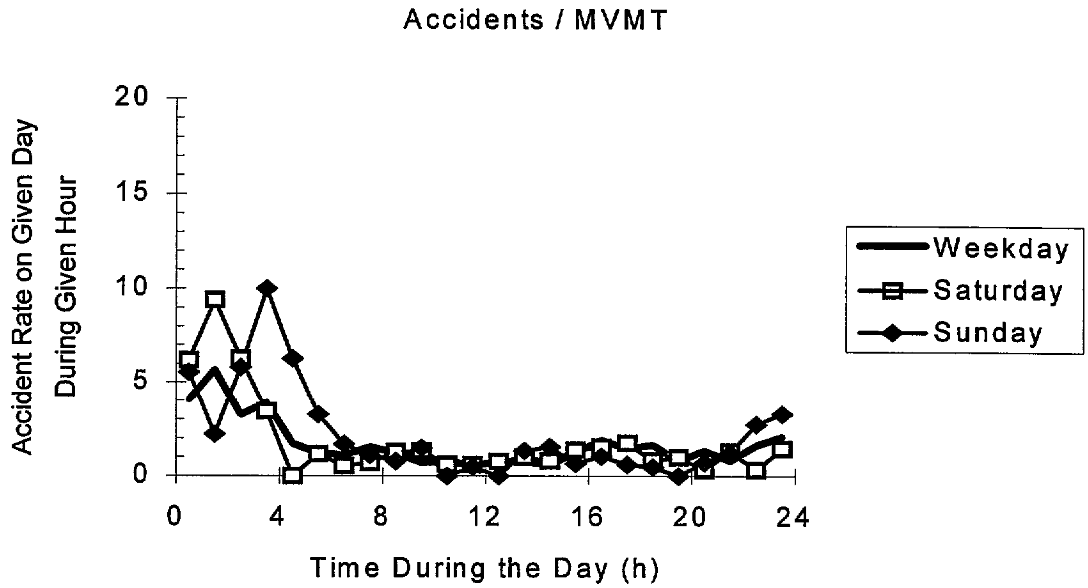
1 mi=1.61 km

Figure 14. Accident frequencies on weekdays, Saturdays and Sundays.



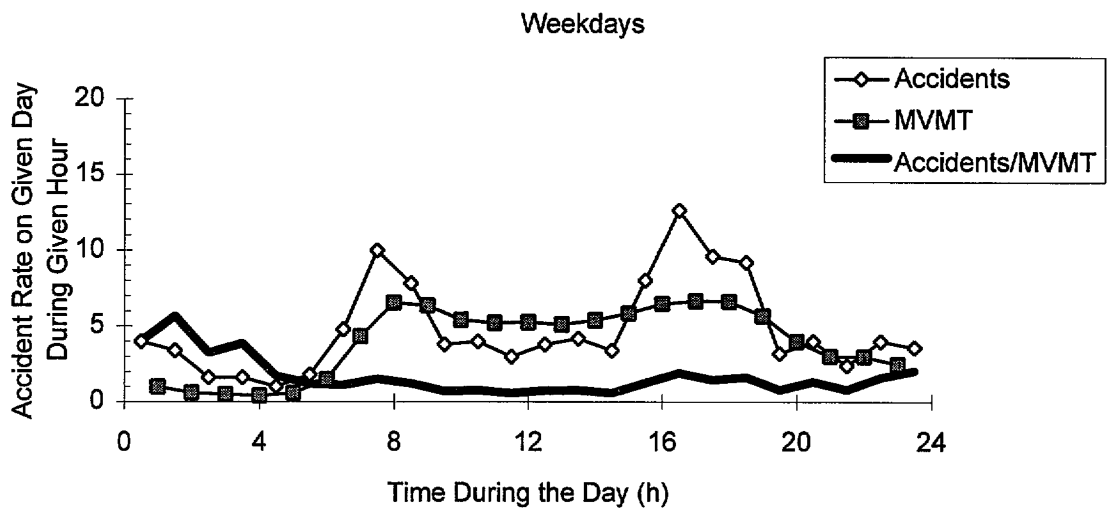
1 mi=1.61 km

Figure 15. Traffic flow characteristics on weekdays, Saturdays and Sundays.



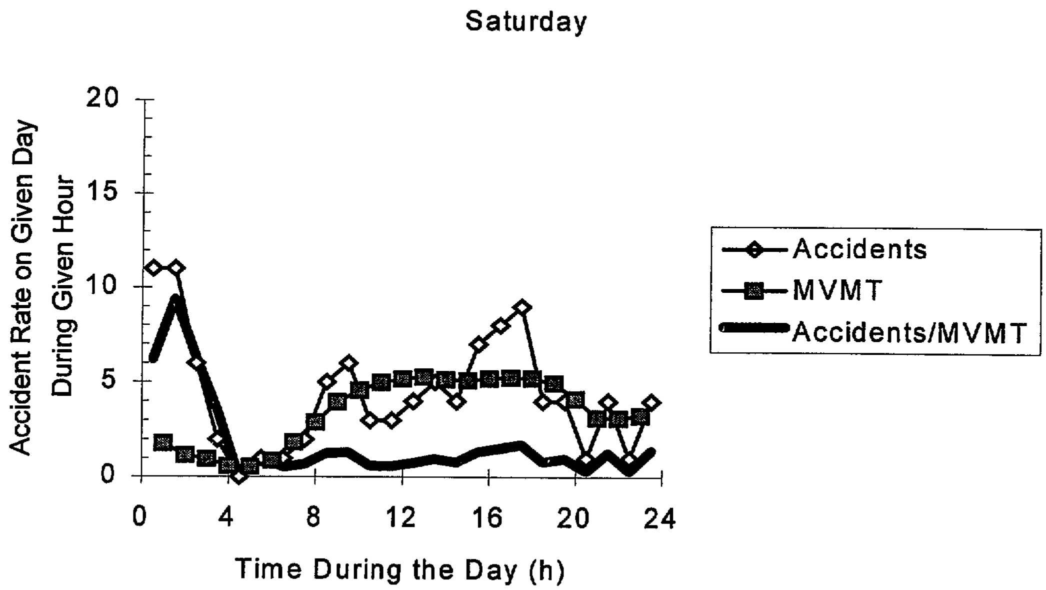
1 mi=1.61 km

Figure 16. Accident rates on weekdays, Saturdays and Sundays.



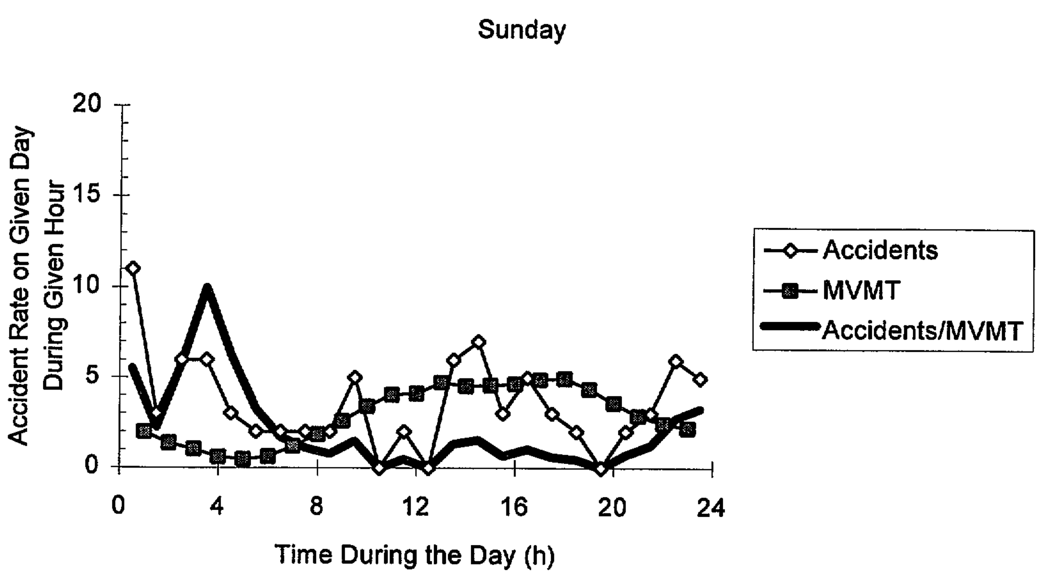
1 mi=1.61 km

Figure 17. Accidents, traffic flows and accident rates on weekdays.



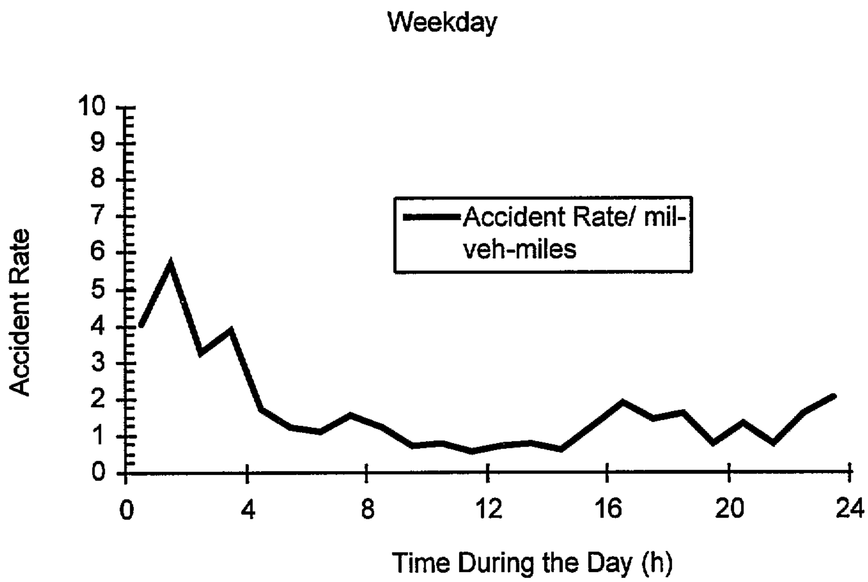
1 mi=1.61 km

Figure 18. Accidents, traffic flows and accident rates on Saturday.



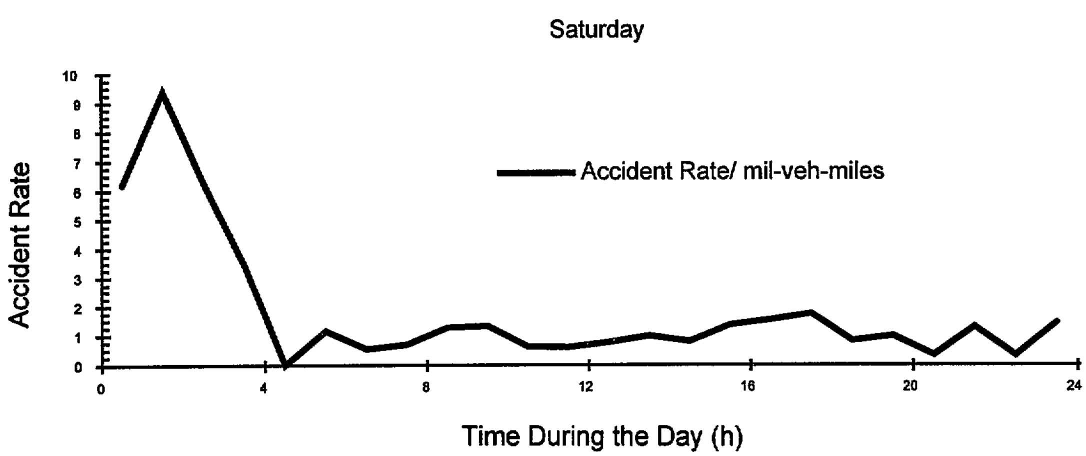
1 mi=1.61 km

Figure 19. Accidents, traffic flows and accident rates on Sundays.



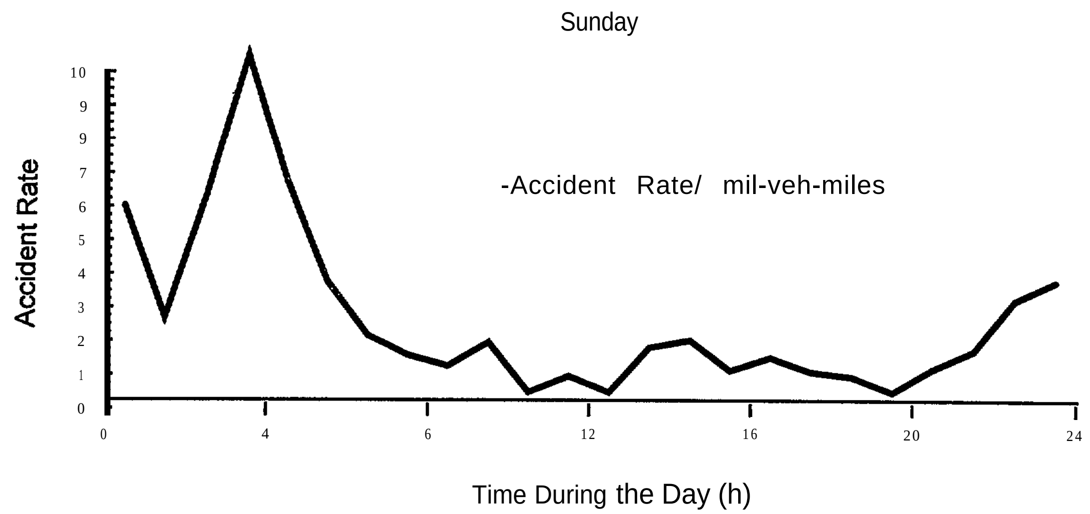
1 mi=1 km

Figure 20. Accident rates on weekdays.



1 mi=1.61 km

Figure 21. Accident rates on Saturday.



1 mi=1.61 km

Figure 22. Accident rates on Sundays.

SUMMARY

The above analysis leads to the following observations and conclusions:

a. The analysis of accidents is complicated by several factors, including the fact that many accidents are not reported, that the level of under reporting is likely not consistent for all accident types, that the mix of single versus multi-vehicle accident rates varies from one facility type to another, and that the number of fatalities per accident also varies in a similar fashion.

b. Given the above limitations of the data, it can be noted that urban roads are safer than rural ones, and that higher class roads are safer than lower class roads. It cannot be determined to what extent a difference in traffic demand or a difference in geometric conditions is responsible for this facility type of effect, but the source of the effect is largely irrelevant in terms of the design of an IVHS system.

c. The fact that accidents are rather rare events, makes it difficult to observe statistically significant differences in accident rates for any conditions for which less than 1.6 to 8 million veh-km (1 to 5 mvm) of exposure are available. The TravTek experiment, which involved less than 1.6 million veh-km (1 mvm) of travel per condition, provided insufficient mileage to discriminate changes in accident rate which were less than an order of magnitude different than the average rate.

d. The 41.8 km (26 mi) of I-4 in Orlando typically experience the same amount of mileage driven between 2 and 6 p.m. on most weekdays as was experienced by TravTek cars during the entire TravTek experiment. Consequently, using I-4 data for an entire year provided a much larger data base from which inferences could be drawn. Specifically, it was found that during the a.m. and p.m. peaks on weekdays the accident rate was higher than during off-peak conditions, where this increase was found to be similar to that found in the literature.

e. Literature and data on the effect of traffic congestion on arterial accident rates indicated that accident rates on arterials increase by a factor of 1.25 when congestion is present. There were not sufficient data available on the Orlando traffic network to calibrate this relationship as there were for the freeways. Part of the difficulty in establishing a relationship between congestion and accident rates on arterials is due to the difficulty in defining the level of congestion on an arterial with multiple intersections and multiple intersection approaches, some of which may always experience some form of queueing. The literature does indicate that arterials which have a higher AADT will experience a higher accident rate, but this increase is not linked directly to the increased presence of congestion.

f. For subsequent analyses in this paper, the base accident rates presented in table 8 are used for uncongested conditions. Values from this table are employed in the INTEGRATION modeling studies where risk is estimated as a function of level of market penetration and level of traffic demand. The factors for the effects of congestion on accident risk found in the literature are used in the INTEGRATION model to estimate accident risk under conditions of traffic congestion. The factor for freeways was calibrated with empirical data from Orlando; however, no data were available for calibrating the factor for the arterials.

EVALUATION OF TRAVTEK OPERATIONAL TEST INCIDENTS AND ACCIDENTS

The TravTek system was driven by a wide range of drivers under varying conditions. This section of the report summarizes incident/accident statistics and other relevant information for:

1. Renters (Bl),
2. Local Drivers (B2),
3. Drivers in the controlled field studies (C 1, C2, and C3), and
4. Drivers on the Evaluation Team and special visitors (or VIP's).

As part of the TravTek evaluation, incident and accident reports were maintained for the 1 year operational test. The reports are the AVIS Accident/Incident Reports, Driver's Report of Traffic Crash, Florida Uniform Traffic Citations, and TISC reports. There were no post incident/accident interviews conducted with the TravTek drivers. Therefore, the available data are incomplete in many cases, especially for accidents that did not include a Florida Uniform Traffic Citation.

The entire fleet of 100 TravTek vehicles had a total exposure of approximately 2.25 million km (1.4 million mi) during the 1 year operational test. The first 2 months of the operational test were considered a "shake down" period for the system. Therefore, the analyses in this report considers the 10 month period following the initial shake down of the system. The total exposure for this 10 month period is approximately 1,887,978 km(1,172,657 mi).

As was noted in the previous section of this report, more than 2.42 million veh-km (1.5 mvm) of data need to be collected before the lower bound of the 95 percent confidence limits (about the accident rate statistic) exceed 0.0. In other words, the number of vehicle km driven in the TravTek operational test presents limitations on the degree of reliability of the resulting accident statistics (i.e., vehicle involvement crash rates per million vehicle km). Furthermore, if one subdivides the sample into Renters, Local Drivers, etc., the reliability of the accident statistics is even further degraded. The results presented in this report with respect to TravTek accident statistics must be interpreted with caution given the relatively low level of exposure (approximately 1.88 million veh-km (1.17 mvm)).

This section presents an analysis of TravTek incidents/accidents in the following manner:

1. A surnmary of all TravTek incidents and accidents is presented.
2. All available information on each incident/accident is presented and summarized. Analyses of a subset of in-vehicle data logs for TravTek accidents is presented (the logs will be used to examine drivers' interaction with the system prior to the accident).
3. TravTek accident/incident rates are compared with AVIS non-TravTek vehicles for Orlando and the nation.
4. Exposure estimates are provided for Renters, Local Drivers, drivers in the System Effectiveness Studies, and Evaluation Team personnel.
5. Vehicle crash involvement rates are presented for Renters, Local Drivers, drivers in the System Effectiveness Studies, and Evaluation Team personnel.

6. Vehicle crash involvement rates for TravTek drivers are compared against national statistics employing appropriate adjustments (taking into account the fact that national statistics underestimate actual vehicle accident involvement rates).
7. Summary of the results of the analyses presenting conclusions regarding the potential safety impact of TravTek in-vehicle systems will be presented.

TRAVTEK INCIDENTS/ACCIDENTS

There were a total of 14 incidents/accidents involving TravTek vehicles during the 10-month operational test phase. Table 11 presents a list of the reported incidents/accidents. There were no incidents or accidents reported for the Local Drivers or drivers in the System Effectiveness Studies. Out of the 14 reported incidents, 10 involved crashes. Three of the crashes involved Rental Drivers, and the other seven involved Evaluation Team members or VIP's. Table 12 lists the crashes as a function of driver status and whether the crash occurred on a private or public road. Details regarding each of the TravTek incidents and accidents are presented in a subsequent section in this report.

Table 11. Number of crashes on public and private roads.

Driver Status	Private Road	Public Road	Total
Renter	2	1	**3**
Local	0	0	**0**
System Effectiveness	0	0	**0**
Other	2	5	**7**
Total	**4**	**6**	**10**

Summary of the TravTek Incidents/Accidents

None of the reported crashes involved bodily injury. Furthermore, with the exception of one VIP driver, no other drivers mentioned TravTek features or functions in the accident report forms. The three crashes involving Rental drivers included two crashes on private property (parking lots) where the TravTek vehicles were stopped in traffic as it was struck by another vehicle.

Examination of in-vehicles log for the above VIP driver showed frequent attempts to use of the ZOOM IN feature while the vehicle was in drive. This function is not available to the driver while the vehicle is in drive. Report from the TISC operator for this accident indicates that the driver was using the cellular phone at the time of the crash. The driver was using the cellular phone to request information from the TISC operator on the use of the ZOOM IN feature (while the car was in drive). The location of this accident is noted as an accident "black hole." This is an intersection with a high accident rate. Finally, the TravTek driver involved in this crash was cited for careless driving. Based on the available evidence it is difficult to identify the use of TravTek features or functions as the primary causal factor in this accident. This driver was engaging in several behaviors that diverted attention away from the roadway while engaging in a turning maneuver.

These behaviors included use of the cellular phone, talking with a TISC operator, and attempting to use a TravTek function that was designed not to function while the vehicle was in motion. This combination of behaviors plus other factors (e.g., engaging in a turning maneuver in a potentially dangerous intersection) led to the accident.

Seventy percent of the accidents in TravTek were accounted by the Other Driver category. This category includes experimenters, TravTek partners, AVIS employees, and VIP drivers. These drivers were generally testing the system, and their use of the system may not be representative of the “average” user.

The entire population of drivers in TravTek drove approximately 1,887,978 km (1,172,657 mi) during the 10 month test phase of the program. In contrast, Pathfinder reports approximately 112,700 km (70,000 mi) driven with 8 property damage crashes. (12) The Pathfinder system, drivers, and traffic network are not directly comparable to the TravTek; however, it represents the only available source of data for another ATIS operational test.

Accident/Incident Rates for Comparable AVIS Non-TravTek Vehicles

The Safety Evaluation test plan calls for comparing TravTek accident rates against comparable vehicles and drivers without TravTek devices that drove in Orlando during the operational test period. In other words, a proper comparison group for the largest population of TravTek drivers (the renters) should be renters of non-TravTek AVIS vehicles in Orlando. Research by Perel indicates that vehicle familiarly is an important factor in crash involvement’s. (13) For example, drivers with fewer than 805 km (500 mi) of experience with a vehicle are approximately 2 to 3 times more likely to be involved in crashes than would be expected. (13) Thus, renters who tend to be unfamiliar with the rental vehicle may be more likely to be involved in accidents relative to those driving their own familiar vehicle. Vehicle familiarity may be a more critical factor for ATIS equipped vehicles where the drivers are unfamiliar with the normal vehicle controls, blind spots, etc. as well as the ATIS devices.

Data on accident rates and exposure for AVIS non-TravTek rentals are not available. The available data from AVIS are for “incidents.” According to AVIS, an incident includes crashes, hail damage, theft, etc. AVIS also provided mileage data for the TravTek fleet of 100 vehicles from March 92 to February 93. The AVIS estimate for TravTek km (2,249,473 km (1,397,188 mi)) does not include 16,100 km (10,000 mi) driven by the camera car. The adjusted estimated number of km driven by the TravTek vehicles is 2,265,573 km (1,407,188 mi) (1,887,978 km (1 ,172,657 mi) for the lo-month operational phase of the program). Table 13 presents a summary of TravTek and AVIS incidents. The AVIS incident data are for Orlando and for the nation. It should be noted that the exposure numbers (miles driven) for the Orlando non-TravTek fleet was estimated by AVIS. Monthly mileage was estimated by multiplying the number of rentals against the average rental mileage.

Table 13 shows that incident rates per mvm were 11.94, 56.26, and 17.59 for TravTek, non-TravTek Orlando, and non-TravTek nation, respectively. The high incident rate for non-TravTek Orlando rentals is attributed by an AVIS analyst to the hail storm that occurred the month prior to the start of the TravTek operational test. AVIS was not able to remove the hail damage incidents from their Orlando incident count. The table shows that TravTek is lower than Orlando and the Nation with respect to incident rates.

Table 12. Summary of TravTek incidents/accidents during operational test phase.

Date	ID	Time	Weather	Road Type	Crash	Ticket	Driver Status	Comments
7/14/92	27371	12:30	?	Public	Yes	No	R*	TravTek car was struck on right door.
6/2/92	21371	12:50	?	Public	Yes	Yes	VIP**	"After making left turn I was looking at the TravTek computer screen, glanced up, saw a car stop-applied brakes and hit the rear end of car."
6/13/92	26631	21:55	Raining	Private	Yes	No	R	"I was following directions of person employed to direct traffic out of Sea World when a bus backed into the side of our rental car. We (myself and the employee at Sea World) tried to get the bus to stop but we were not successful."
6/21/92	?	?	?	Public	No	No	ET***	Vandalism to GPS antenna while car was parked.
8/3/92	?	14:10	Sunny	Public	Yes	Yes	ET	TravTek car was struck by car backing out of a driveway.
8/14/92	?	9:00	Clear	Private	Yes	No	ET	TravTek car was struck on right door at car wash located at AVIS QTA.
8/16/92	95181	?	?	?	?	?	R	Unreported damage to right front fender.
9/1/92	?	?	?	?	?	?	R	Unreported damage to driver door.
9/13/92	?	16:40	Raining	Public	Yes	Yes	ET	TravTek driver cited for failure to yield right of way. Car was struck on right side while going through intersection.
9/17/92	31841	?	"Good"	?	?	No	R	Report indicates damage to rear and right rear fender of car. No accident report filed.
1/11/93	?	9:30	?	Public	Yes	Yes	ET	TravTek driver cited for improper change of lane. Car was struck on right door while departing toll station and in the process of changing lanes.
2/10/93	?	17:44	"Good"	Public	Yes	Yes	ET	Struck on left front fender while turning left. Other driver cited for failure to yield.
3/12/93	?	20:45	"Good"	Private	Yes	No	ET	TravTek car struck on left door while driving through parking lot.
3/14/93	41351	10:30	Clear	Private	Yes	No	R	Was rear ended while stopped in line approaching the parking gates at Universal Studios.

* Rental User

** Non-Subject Driver

*** Evaluation Team member

Table 13. TravTek and non-TravTek incident statistics.

Condition	Number of Incidents	Number of Miles	Incidents/mvm
TravTek	14	1,172,657	11.94
Non-TravTek Orlando	1,247	22,164,979	56.26
Non-TravTek Nation	57,079	3,244,779,425	17.59

1 mi=1.61 km

For testing the difference between two accident rates, the following statistic can be employed:

Z= In (Rl/R2) / (l/N1 +l/N2)^.5

Where;

R1 &R2: rates for the two samples being compared(e.g., TravTek versus Orlando)

N1 &N2: the number of incidents/accidents for the samples being compared

Comparison between TravTek and non-TravTek Orlando AVIS rentals yields a Z equal to 5.77 ($p<0.001$). This result indicates that the TravTek incident rate is statistically lower than the rate for the non-TravTek AVIS rentals in Orlando. Comparison between TravTek and non-TravTek Nation rates yields a Z equal to 1.45 ($p>0.05$). This indicates that the TravTek incident rate is not statistically different from the rate for non-TravTek AVIS rentals based on nation-wide statistics.

The results presented in table 13 show that at a global level TravTek may have been as safe or safer than driving in a non-TravTek equipped vehicle. However, the low number of km driven for TravTek, and AVIS' definition of "incident" make these results more suggestive than conclusive.

EXPOSURE ESTIMATES

The exposure number presented for TravTek thus far aggregates across all studies and driver types (e.g., renters, local drivers, VIP's, evaluation team members, subjects in controlled field studies). This section presents estimated km driven as a function of the different categories of drivers.

Miles driven for the Rental, Local, and System Effectiveness studies were estimated using in-vehicle log data. For the Renters, vehicle logs for 73 Services, 309 Navigation, and 576 Navigation Plus drivers were analyzed. The average number of trips and average trip length was computed for the S, N, and N+ conditions using in-vehicle log data. The number of drivers in the S, N, and N+ conditions were 3 14,684, and 971, respectively. The number of drivers in the above conditions was determined by using the in-vehicle logs. Total km driven for the S, N, and N+ conditions were estimated by computing the product of average number of trips, average trip length, and number of drivers for each respective condition.

For the Local drivers, vehicle logs for 21 N, and 29 N+usage periods were analyzed. For the System Effectiveness studies (Yoked and OTNS), a subset of in-vehicle logs were sampled to estimated number of km driven by subjects in the studies. For the Camera Car Study, the odometer reading was used where the km driven by the experimenter were subtracted from the reading. For the Other category, km driven was computed by subtracting the estimated km driven (the above categories) from the total number of estimated km driven by the TravTek fleet. Table 14 presents the estimated number of km driven for the different categories of drivers in the TravTek operational test.

Table 14. Estimated number of miles driven.

Condition	Estimated Miles Driven	Percent of Total Miles
RENTERS	541,773	
Services	97,576	8.32%
Navigation	189,350	16.15%
Navigation +	254,847	21.73%
OTNS	22,614	1.93%
YOKED	11,412	.97%
CAMERA	7,140	.61%
LOCAL	107,288	9.15%
OTHERS	482,430	41.14%
Total	1,172,657	

1 mi=1.61 km

The Other category included the second highest number of km driven for TravTek. This category included Evaluation Team members as well as VIP’s. In addition, any data collection that included “pilot” subjects would fall in this category.

COMPARISON OF VEHICLE CRASH INVOLVEMENT RATES

One method by which to evaluate the safety of an in-vehicle system (e.g., ATIS displays and controls, car phones) would be to compare the accident involvement rates for vehicles equipped with “gadgets” versus those not equipped with gadgets. In addition, a wide range of relevant variables known to affect accident rates would be statistically controlled through proper sampling. For example, the groups would be equated for such variables as driver age, driving experience, and vehicle familiarity. In addition, such factors as the type of roads driven (e.g., freeways versus surface streets), rural versus urban km driven, time of day, visibility conditions (day versus night), etc. would be statistically controlled or extremely large samples would be gathered where these factors would be “averaged” across the two samples. In the case of TravTek, although approximately 1.93 million km (1.2 million mi) were traveled, when compared to national statistics on the order of trillions of km, the TravTek km can be considered as few. Moreover, a comparison group matched along relevant variables was not available.

Earlier in this report, the results of the Pathfinder operational test with respect to safety were briefly discussed. In Pathfinder there were approximately 112,700 km (70,000 mi) driven with 8 property damage accidents. Though Pathfinder and TravTek differ along many dimensions related to safety (e.g., driver characteristics, traffic network, in-vehicle interface design), Pathfinder represents the only other operational test of an ATIS were results are available. The crash rates from Pathfinder and TravTek can be compared using the formula previously used in this report to compare TravTek incident rates against non-TravTek AVIS rentals incident rates. Comparison of the Pathfinder and TravTek accident rates yield a value of Z equal to 5.31 ($p<.01$). This indicates that the accident rate for TravTek (including all drivers) is statistically lower than the rate observed for Pathfinder.

An additional data base for evaluating the results of TravTek from a safety perspective includes the General Estimates System. (7) An extensive summary of accident statistics are provided in the GES 1991. However, the statistics provided in this report are for police-reported traffic crashes. Research reported by Miller et al. indicates that there may actually have been 2.5 times as many accidents as are reported in the national statistical data bases. (9) This finding suggests that GES accident statistics are not the proper comparison for the TravTek accident rates. In TravTek, all accidents are "reported."

The following presents a series of comparisons between TravTek and GES vehicle crash involvement rates. A correction factor of 2.5 was applied to the GES rates (e.g., multiply GES rates by a factor of 2.5) to make them more comparable to the TravTek reported rates.

For the following analyses, crash vehicle involvement rates per mvm are used. This is the statistic used in the previous section of this report. Use of the same statistic across reports will allow for better comparisons of results.

The TravTek network is in an urban area. The vehicle crash involvement rate for urban areas was derived in the previous section. This rate is equal to 3.1 million veh-km (1.926 mvm). Again, this statistic is an estimate for police-reported crashes. For the purpose of analysis, a rate of 4.82 (1.926 x correction factor of 2.5) is used to compare the population crash involvement rate against the TravTek rates. It should be noted that drivers of TravTek vehicles sometimes drove outside of the TravTek coverage area. The traveled km inside and outside of the TravTek coverage area were not estimated for the one year operational test.

Review of Statistical Procedure

For the computations that follow, vehicle involvement rate (probability) as a function of vehicle km driven was assumed to be distributed as a Poisson. The following formula yields probabilities for a Poisson distribution:

$P(R=r \mid \lambda, p) = (e^{-\lambda t} (\lambda t)^r)/r!$

λ is the number of vehicle crash involvement's (population parameter)

t the number of km driven (in mvm)

r the observed number of crashes

Figure 23 presents an example probability distribution for $\lambda = 4.82$ and $t=1$ (1 mvm). The shape of the distribution will vary as a function of t and λ. The mean of the distribution is equal to λt with the variance equal to the mean.

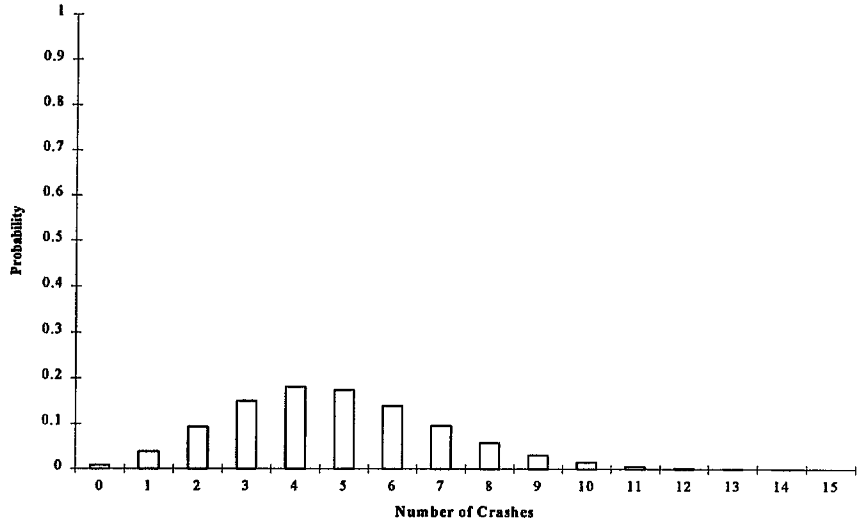


Figure 23. Probability distribution of crashes for a population with mean equal to 7.76/million veh-km (4.82/mvm) (1 mvm of exposure).

Total Crashes

There were a total of 10 crashes for the TravTek operational test. This would yield a crash rate of 13.73/million veh-km (8.53/mvm). Figure 24 presents the probability distribution for all TravTek drivers where the number of km driven was 1.89 million veh-km (1.172 mvm). As can be seen, the average for TravTek is shifted to the right relative to figure 23. The reason for this is that the figure for TravTek is based on 1.89 million veh-km (1.173 mvm) rather than 1.61 million veh-km (1 mvm). As exposure increases, we can expect to see more crashes for a given sample from a population.

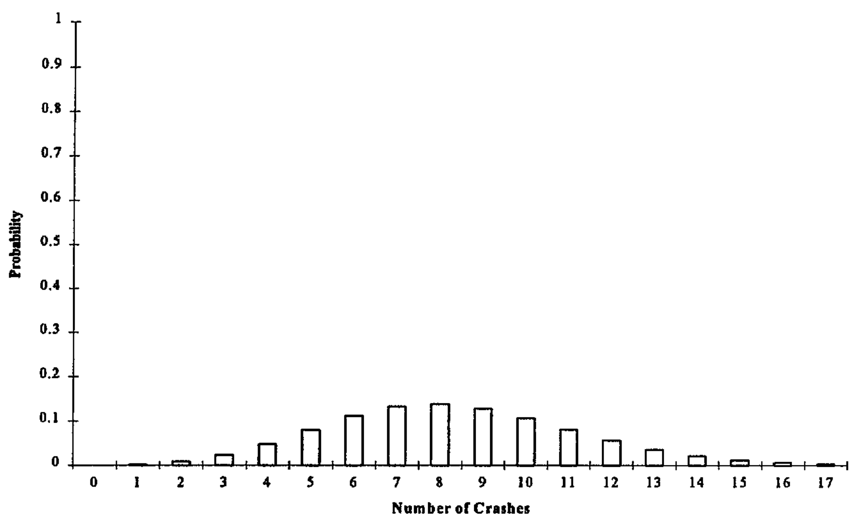


Figure 24. Probability distribution for total number of crashes for all drivers in TravTek (1.89 million veh-km (1.173 mvm)).

For the TravTek operational test, the probability of 11 or more crash involvement's is equal to 0.03. This indicates that the TravTek crash involvement rate (when the population average is adjusted by a factor of 2.5) is statistically higher than the adjusted population average. The total number of crashes for TravTek included counting crashes that occurred on private property (e.g., parking lots) and included minor damage. Even though a correction factor of 2.5 was applied to adjust for the fact that the number of police-reported crashes represents an underestimate of the true crash rate, inclusion of minor accidents on private property is likely to result in an additional and unrealistic inflation of the TravTek accident rate.

If one were to consider only those crashes that occurred on public roads, the rate for TravTek would be based on 6 crashes. This yields a crash involvement rate of 8.23/million veh-km (5.1 1/mvm). This rate is not statistically higher than the adjusted population average of 7.76/million veh-km (4.82/mvm). The probability of 7 or more crashes with 1,887,978 km (1,172,657 mi) of exposure is 0.337.

As was mentioned in the previous section of this report, use of crash rates for evaluating the safety impact of an in-vehicle device, or other variables such as changes to highway design require a large volume of data to be recorded where exposure needs to be several magnitudes greater then was observed in TravTek. Evaluation of changes to highway design that use accident statistics are generally conducted over several years. Furthermore, accident data are available for the specific segment of roadway prior to the implementation of design changes. For example, the Accident Research Manual recommends the use of experimental designs such as before/after with randomized control groups for evaluating the impact of changes to highway design on safety. [14] For these evaluations, groups represent multiple sites where highway design changes have or have not been implemented.

If we were to model our experimental design to meet the recommendations from Council et al. in the case of evaluating the impact of an in-vehicle device on safety where crash data are employed, one would need two groups of drivers. [14] One group would use the in-vehicle device and the others would drive the same type of vehicle without an in-vehicle device. Both groups would drive the vehicles for a period of time without an ATIS device to obtain baseline measures of accident rates. After the baseline measures are collected, one group would have the ATIS device installed and the other would continue to drive without the device. Finally, the device would be removed from the vehicles and data on crashes would once again be collected for both groups. This type of experimental design would only entail the comparison of an ATIS equipped vehicle against a control condition. (TravTek included several different configurations of the in-vehicle device.) Furthermore, based on the analyses performed in the previous section of this report, exposure data in the order of 16.1 million veh-km (10 mvm) or greater, would be required for this type of design.

The experimental design employed for the Yoked Driver Study presents one of the better methodologies for evaluating safety in the TravTek study. The study employed a set of preselected O/D's where the drivers were generally exposed to the same environmental and roadway conditions, the drivers in different configurations drove during the same time of day and experienced similar traffic conditions, and drivers were randomly assigned to the conditions.

However, there were no crashes in the Yoked Driver Study and too few km were driven in each condition to obtain reliable statistics for crash data if they would have occurred.

Another issue that should be considered when employing crash data to evaluate the safety of an in-vehicle device, is the bias of the analytical procedure for detecting negative effects when few km of exposure are collected. For example, in order to demonstrate greater safety using the above statistical approach, only 1 crash could have occurred. The probability of 1 or zero crashes for the entire TravTek sample would be equal to .024 given an adjusted population average and 1.89 million veh-km (1.173 mvm) of exposure. On the other hand, the probability of 2 or less crashes would be 0.08, a not statistically significant effect.

Crashes per Driver Group

In a previous section, number of km driven was estimated for:

- Renters
- Local Drivers
- OTNS
- Camera Car Study
- Yoked
- Others

The following presents statistics for these separate groups of drivers; however, the validity of the statistics will be extremely questionable due to the reduced exposure levels for each subgroup. As was discussed earlier, 2.42 million veh-km (1.5 mvm) represents a minimum for computing accident statistics. The total number of km for the TravTek operational test falls below this minimum.

Renters

There were three crashes for the Renters where 872,255 km (541,773 mi) were driven. This yields a vehicle crash involvement rate of 8.9 million veh-km (5.53/mvm). As shown in table 3, the km driven for the Renters was divided among the S, N, and N+ conditions. The S condition represents a control condition where none of the TravTek navigation or guidance displays were available to the drivers. There were no crashes reported for the S condition. Figure 25 presents the probability distribution for the S condition. The probability of obtaining zero crashes for this condition is equal to 0.625. This indicates that the crash rate for the S condition is not significantly different from the population crash rate. With this low level of exposure, zero crashes is not an unusual finding from a statistical sense.

There were three crashes for the renters in the N and N+ conditions. The combined number of km driven for these two conditions was 715,157 km (444,197 mi). This yields a crash rate of 10.87/million veh-km (6.75/mvm). Figure 26 presents the probability distribution for the Renters in the N and N+ conditions combined. The probability of four or more crashes is equal to 0.17. This indicates that the crash rate for the Renters in the N and N+ conditions combined is not significantly different from the population average. It should be noted that one of these three crashes occurred on private property. If we were to remove this crash from the rate for the N+ and N conditions, the new rate based on two crashes would be equal to 7.25/million veh-km (4.50/mvm). The probability of two or less crashes would be equal to 0.64. Actually, finding exactly zero crashes for the N and N+ condition would be equal to 0.12, indicating that it would not be unlikely to find zero crashes given the level of exposure and an adjusted population rate of 7.75/million veh-km (4.815/mvm).

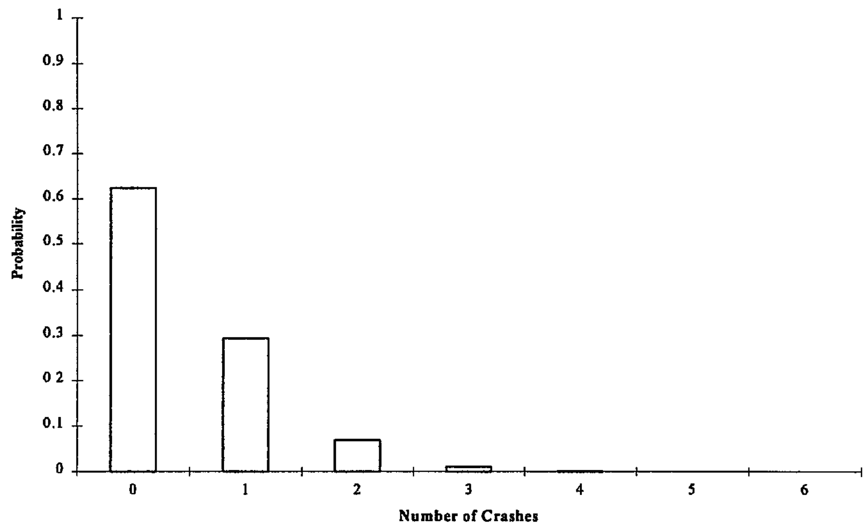


Figure 25. Probability distribution for number of crashes for TravTek Renters Services condition (0.16 million veh-km (0.0976 mvm)).

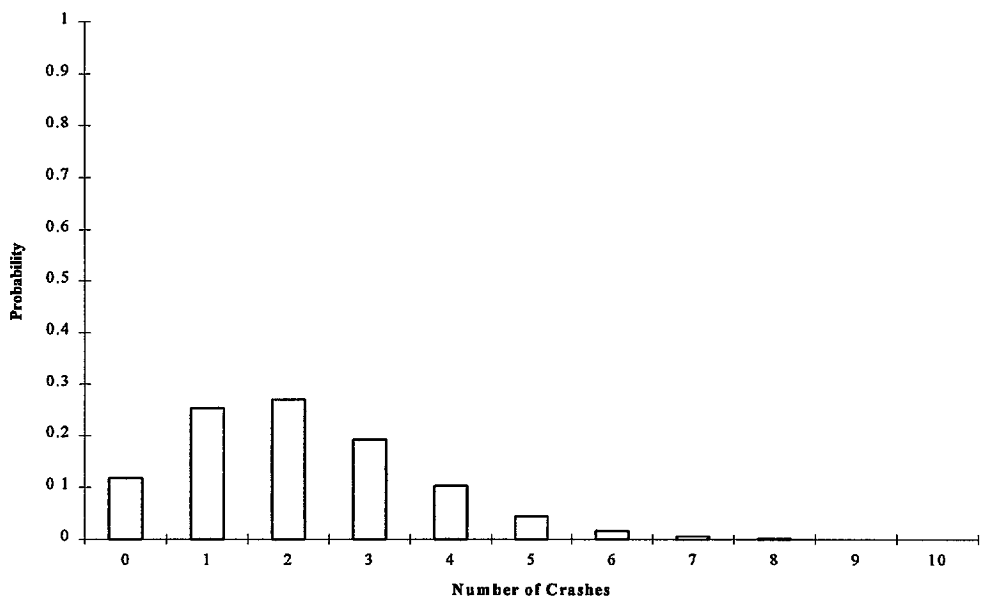


Figure 26. Probability distribution for number of crashes for TravTek Renters N and N+ conditions combined (0.72 million veh-km (0.4442 mvm)).

System Effectiveness Studies

There were no accidents in the System Effectiveness Studies (Yoked Driver Study, OTNS, and Camera Car Study). For these studies there was an estimated total of 66,277 km (41,166 mi) driven (well below the 2.42 million veh-km (1.5 mvm) minimum). Figure 27 presents the probability distribution for the System Effectiveness Studies using an exposure rate of 0.07

million veh-km (0.0412 mvm). The probability of exactly 0 crashes for an exposure level of 0.07 million veh-km (0.0412 mvm) is equal to 0.82. Given the low exposure level, it is not unlikely to find 0 crashes. The results indicate that the crash rate for the System Effectiveness Studies was not statistically different from the population.

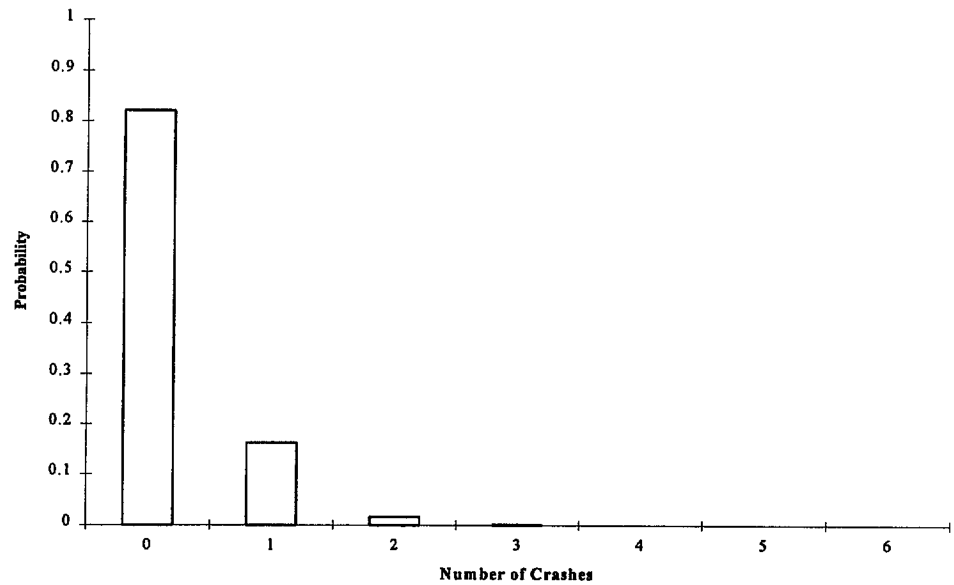


Figure 27. Probability distribution for number of crashes for TravTek System Effectiveness Studies (0.07 million veh-km (0.0412 mvm)).

Local Driver

There were no accidents for the Local Driver Study. For this study there was an estimated total of 172,734 km (107,288 mi) driven (well below the 2.42 million veh-km (1.5 mvm) minimum). Figure 28 presents the probability distribution for the Local drivers. The probability of exactly 0 accidents with 0.17 million veh-km (0.107288 mvm) of exposure is equal to 0.60. The results indicate that the observed number of crashes (zero) for the Local drivers is not statistically different from the population average.

Other Drivers

The Other Driver category includes Evaluation Team members and drivers classified as VIP's. These drivers drove approximately 776,712 km (482,430 mi) during the 10-month operational test (well below the 2.42 million veh-km (1.5 mvm) minimum). There were a total of seven crashes for this subgroup of drivers. The vehicle crash involvement rate for this subgroup is 23.36/million veh-km (14.51/mvm). Figure 29 presents the probability distribution for the Other Driver category. The probability of eight or more crashes is equal to 0.0028. This result indicates that the crash rate for the Other Driver category is statistically greater than the population average. If we removed the crashes on private property from the rate computation, the rate for the Other Driver category would be 16.68/million veh-km (10.36/mvm), and the probability of six or more crashes would be equal to 0.01. This new adjusted rate would still represent a statistically higher rate than expected by chance alone.

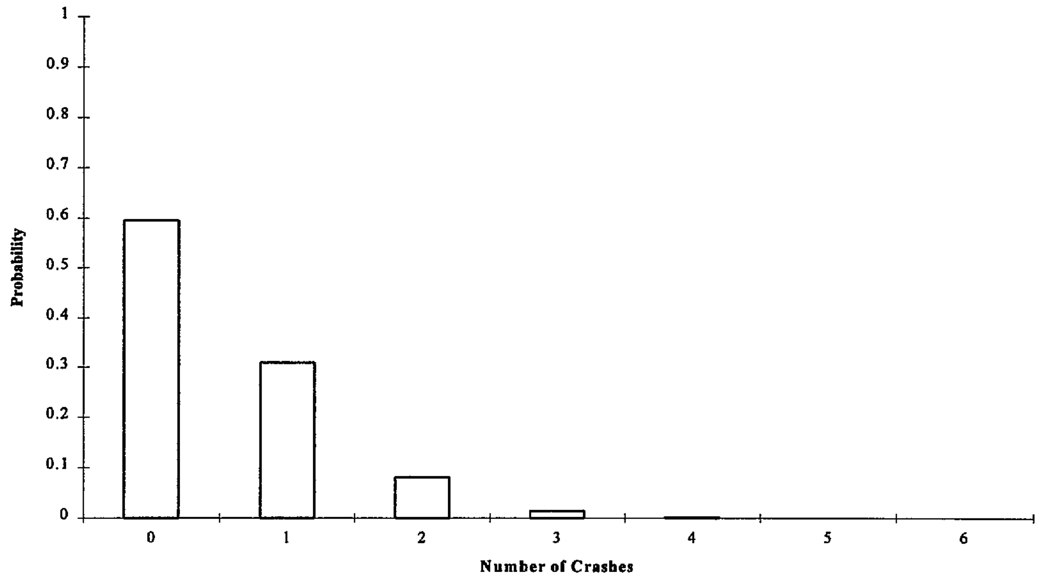


Figure 28. Probability distribution for number of crashes for TravTek Local Drivers (0.17 million veh-km (0.107822 mvm)).

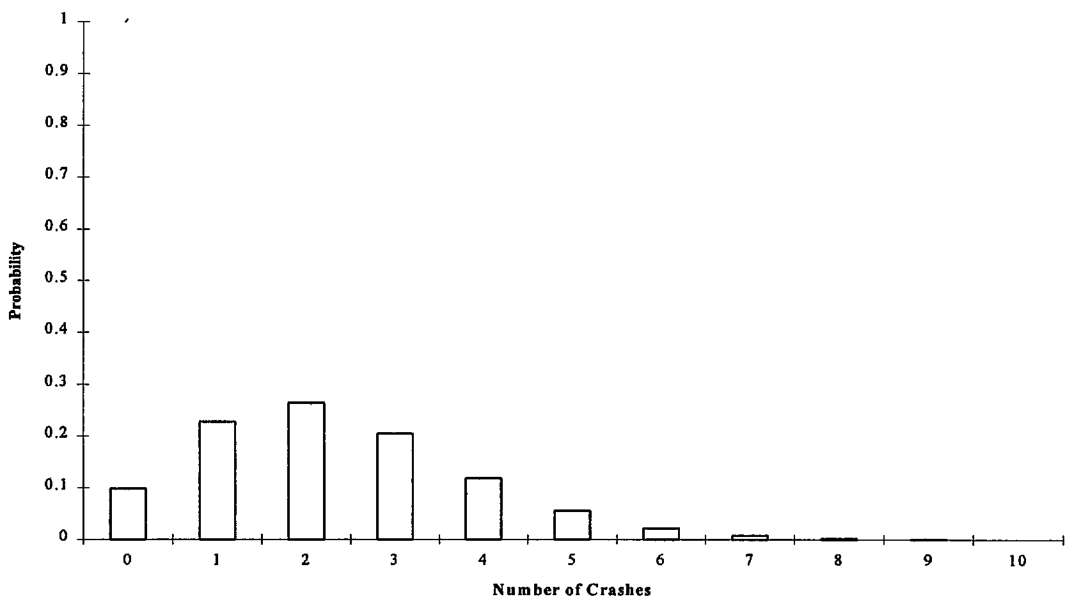


Figure 29. Probability distribution for number of crashes for TravTek Other driver category (0.78 million veh-km (0.4824 mvm)).

SUMMARY

The analysis presented in this section suggest that TravTek drivers, with the exception of those in the Other Driver category, did not have a greater accident rate relative to the GES estimate for urban vehicle involvement rates. These results provide converging evidence for the safety of ATIS in-vehicle systems and should not be interpreted in isolation. The use of statistics such as vehicle crash involvement rates per mvm requires large samples (e.g., greater than 2.42 million veh-km (1.5 mvm) of exposure). Also, an appropriate comparison sample that is equivalent on important variables known to affect accident rates (e.g., age of driver, vehicle familiarity, environmental conditions, traffic conditions) needs to be used. In the case of TravTek, none of the above assumptions were met.

Comparisons were made between the crash rates observed in Pathfinder and TravTek. These comparisons must be interpreted with caution given the low level of exposure and the differences between the two operational tests. The Pathfinder system was a navigational system that also provided real-time traffic information. TravTek provided route guidance information in the form of voice and visual displays (Route Map and guidance display) of information in addition to navigation and real-time traffic information. In addition, the Pathfinder system employed the Etak navigation display which has been shown through previous research to require significant visual attention while driving. [15] Additional research conducted under the System Effectiveness Studies (OTNS, and Camera Car Study) in TravTek will provide converging evidence on the safety impact of the system.

The use of crash data to assess the impact of roadway treatments on safety generally requires multiple years of crash data to be recorded. In TravTek, data were collected for a 1 O-month period for a small fleet of vehicles (small for this type of analyses technique). The methods presented in this report provide a technique for assessing the safety impact of in-vehicle displays; however, the study suffers from a lack of data with respect to exposure. As noted earlier, an adjustment factor of 2.5 was used to account for the fact that accidents are under reported in the national data bases. For TravTek, all accidents were “reported.”

The review of the crashes and incidents in TravTek suggests that the system did not pose a serious safety problem. For the entire population of test drivers there were three crashes (Renters, Local drivers, and drivers in the System Effectiveness Studies). Two of these crashes involved TravTek vehicles that were stopped in traffic when they were struck by another vehicle. None of the test drivers mentioned the TravTek system in their accident report forms.

The majority of crashes during the 10-month operational test were for the drivers in the “Other” category which included VIP’s, experimenters, AVIS personnel, and TravTek partners who were testing the capabilities of the system.

Statistical analyses of the TravTek crash data showed that the crash rates for the different studies did not significantly differ from an adjusted population crash rate. That is, crash history for the drivers in the Field and System Effectiveness Studies suggests that the TravTek system did not have a negative impact with respect to safety.

EVALUATION OF SAFETY-RELATED MEASURES

The previous sections of this report have discussed the use of crash statistics for evaluating the safety impact of an ATIS implementation. For the TravTek operational study, there were few crashes and the results indicate that the system was not a safety detractor. This section presents a review of safety-related measures collected across all of the empirical studies.

Performance based measures related to safety have been identified for quite some time. For example, Council et al. discuss such measures as speed variance and vehicle following distance as "proxy measures" for accidents. [14] However, criteria with respect to what represents safe or unsafe performance measures are not available. These "proxy measures" are generally employed in experiments where relative comparisons are made between conditions. For example, a given roadway design leads to longer following distances relative to what was observed before the application of the highway treatment. In the absence of actual accident statistics, this result could be used to suggest that the highway treatment increases safety.

SAFETY EFFECTS DUE TO ROUTE SELECTION VERSUS IN-VEHICLE DISPLAY

From the outset it was noted that the analysis of the safety impacts of the TravTek system needed to be separated into at least two distinct but potentially related components. Specifically, it needed to be determined if the TravTek route guidance system, in an effort to avoid traffic congestion and minimize travel time, would tend to divert traffic to routes which were either less or more safe, and whether such diversions would result in a greater/smaller distance traveled. This factor would reveal if access to ATIS information would permit drivers to indirectly also select routes which were intrinsically safer, and if the extra distance traveled to avoid travel time delay would offset such benefits. The second component consisted of an analysis to determine if, for vehicles traveling an identical distance along the same routes, the simple presence and use of the TravTek system within the vehicle would result in travel which was less or more safe. This factor would capture whether the actual process involved in the provision of ATIS information, by means of the TravTek system compared with the reference Paper Map condition, would have a potentially negative or positive net impact on safety.

This section focuses on the estimation of this second component of this risk assessment, while the next section focuses on both the former factor and the interaction of these two factors. Aside from the conceptual convenience of defining these two explicit factors and the need to treat them as such in a simulation model, the separation of the safety impact in these two components also yields important design implications for future systems. Specifically, if the former route-related factors dominate the differential safety impact of TravTek vs. the reference non-TravTek systems, then in order to (further) improve the safety level associated with ATIS systems, the search for better safety-oriented route guidance algorithms may potentially yield the greatest safety benefits. In contrast, if the gadget factor dominates the differential safety impact, then further research in the human factors elements associated with the in-vehicle display may potentially yield the greatest safety benefits.

It should be noted that the development of the TravTek driver/system interface included considerable human factors research. Rapid prototyping and laboratory research was conducted by General Motors and Hughes to develop an effective interface that was safe to use. For example, functions were divided into pre-drive and drive. The drivers were able to interact with the system's menus for route planing only while the vehicle was parked. Furthermore, functions such as changing the scale of the map display could only be performed while the vehicle was at zero speed. While the vehicle was in motion, the driver interacted with the system through buttons mounted on the steering wheel and had access to voice route guidance instructions thus reducing the possibility of long glances away from the road. (See references 16 and 17 for more detailed discussions of the design of the TravTek driver interface.)

Research to fully explore the relative contribution of the driver/vehicle interface and route guidance algorithms on system safety is outside the scope of the research presented in this report. The TravTek operational test employed a well engineered driver/system interface. The subject population employed for the operational test does not fully represent the general population of drivers. Also, alternative routing algorithms and data sources were not investigated in the study. Figure 31 presents a conceptual design needed to investigate the trade-offs in safety among three relevant variables. That is, a range of driver/system interfaces, routing algorithms, and drivers that vary in terms of safety would need to be investigated. There are methodological and ethical constraints in designing an operational test that would fully explore the relative contribution to safety of the factors presented in figure 30. It would be difficult to scale safety for the above factors in an appropriate manner. A complete exploration of the above factors could be conducted in simulation studies where safety factors could be better managed. The simulation studies could be supplemented with operational tests where partial validation of the simulation results would be performed.

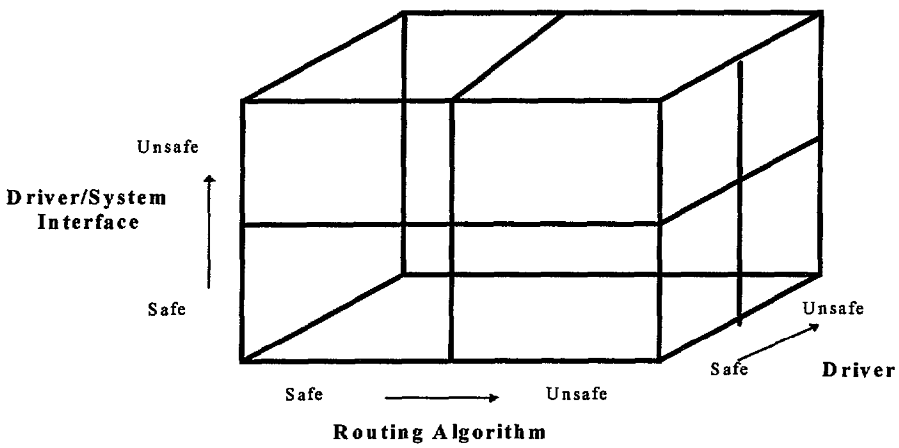


Figure 30. Conceptual operational test design.

As was mentioned in the introduction, TravTek presents components of a fully deployed ATIS. The TravTek system contained IRANS and IMIS components of ATIS. These components are not explicitly designed to increase safety, rather they are designed to make travel more efficient by reducing wasted km of travel and congestion. An ATIS that meets the above design objectives and results in neutral safety effects with respect to the gadget factor, should be judged as an effective system.

SAFETY-RELATED MEASURES

For the TravTek study, a wide range of performance, observer, and ratings data were collected across multiple experiments. The following presents a brief discussion of the measures used as part of the safety evaluation.

Performance Data

Performance data were collected from the Camera Car Study and consisted of such variables as lane deviations, longitudinal acceleration, and eye glance behaviors. The following presents a brief discussion of the performance data that were used in this report.

Unplanned Lane Deviations

An unplanned lane deviation is a face valid indicator of driver inattention and collision potential. In the laboratory, lane deviations were classified and timed from the TravTek lane-track camera record. [18]

Longitudinal Acceleration Measures and Braking Data

Breaking behavior can also provide a sensitive measure of performance. If drivers are looking away from the driving scene and glance back only to realize that an unanticipated event is occurring, the break pedal must be depressed harder and the resulting deceleration is greater than in normal attention situations. Longitudinal deceleration and break pedal activation data were measured as part of the Camera Car Study. [18]

Single Eye Glances Greater Than 2.5 s

Glance duration was recorded and the data were reduced in such a way that each driver glance to the nearest 0.1 s could be identified. Lengths of single glances to the display (map) configuration are of particular interest to system safety. Based on previous research, 2.5 s was used as a criterion to assess instances of unsafe behavior. [18]

Average Duration of Glances to Navigation Displays

The driving task requires constant scanning of the forward roadway, to the left and ri ht of the forward roadway, and to the rear (via mirrors) to drive effectively and defensively. [18]

Observer Data

Observer data consisted of observer reported number of close calls. In addition, for the Camera Car Study the roadway video was analyzed to categorize close calls in a detail manner. Analyses of the roadway video resulted in the classification of close calls in terms of the hazards that were present in the roadway. Also, close calls were correlated with the driver’s eye glance behavior such that close calls could be related to use of the in-vehicle display unit.

Close call data from the TravTek Yoked and OTNS experiments were recorded by an in-vehicle observer. The observers recorded a frequency of events that they felt represented a close call or near miss. In the Camera Car Study a more rigorous methodology was employed to record near-misses. For the purpose of analyses, the following three types of near-miss variables were used from the Camera Car Study:

Driver Error with Hazard Present

The driver commits a safety-related error when an object (e.g., another vehicle, a pedestrian, or guardrail) is present in the environment. "Hazard present" requires that the object is in a close enough proximity to represent a hazard to the test vehicle, but not close enough that an immediate evasive action must be taken to avoid it. [18]

Total Safety-Related Errors

This was the total count of near misses, hazard present errors, and no hazard present errors. Near misses were classified as situations where the driver is startled by a situation and is required to take immediate evasive action in order to prevent an accident. No hazard present errors were those situations where the driver commits a safety-related error, but no close-proximity obstacle is present in the environment.

Risk Assessment Variable (Undesirable Risk)

The Camera Car Study reports the use of the Failure Modes Effects and Critically Analysis (FMECA) method for combining factors such as environmental proximity, potential severity, and number of incidents to assess the safety implications across all of the navigational display conditions. With this analyses method, close calls that were video recorded in the experiment were classified as unacceptable risk, undesirable risk, and acceptable risk. Table 15, reproduced from the Camera Car Study, illustrates how close calls were placed into these three categories.

Driver Self Reports

Driver's self reports consisted of ratings of workload and responses to questionnaire items related to safety.

Questionnaire Data

The TravTek questionnaire contained items that asked driver's to rate the degree to which the TravTek in-vehicle system helped them drive more safely. In addition, questions were asked with respect to the degree to which the TravTek system helped in paying attention to the driving task and also to what degree it interfered. All question were presented with a 6-point scale. For the purpose of analysis, the responses to items were scaled such that a rating of one (1) represented an "unsafe" response and a six (6) indicated a "safe" response.

Workload Ratings

There a wide range of methods are available for the measurement of mental workload. The chapter by O'Donnel and Eggemeier presents a comprehensive review of erformance-, subjective-, and physiological-based techniques for measuring workload.[19] The idea behind using workload measurement techniques, is the fact that primary task performance (e.g., driving a vehicle) may not show degradation as mental workload increases. However, workload measurement techniques that use subjective ratings or secondary tasks, for example, may reflect increases in workload even when primary task performance remains unchanged and at an acceptable level. Workload measurement techniques can therefore be used as predictors of potential primary task degradation.

Table 15. Risk assessment matrix for the safety analysis. [18]

HAZARD RISK KEY	
All Risks Depend on Frequency	
Unacceptable Risk	(grey)
Undesirable Risk	(black)
Acceptable Risk	(white)

Environmental Proximity			
Accident	**Near Miss**	**Driver Error Hazard Present**	**Driver Error No Hazard Present**
Striking an object, at least causing property damage	Narrowly avoid striking object	Inappropriate/ illegal action with close proximal object	Inappropriate/ illegal action with no proximal object

POTENTIAL SEVERITY	
Catastrophic	Death or permanent disability injury
Critical	Injury severe enough to cause hospitalization
Marginal	Injury, but not severe enough to require extended medical attention
Minor	Property damage only, no personal injury

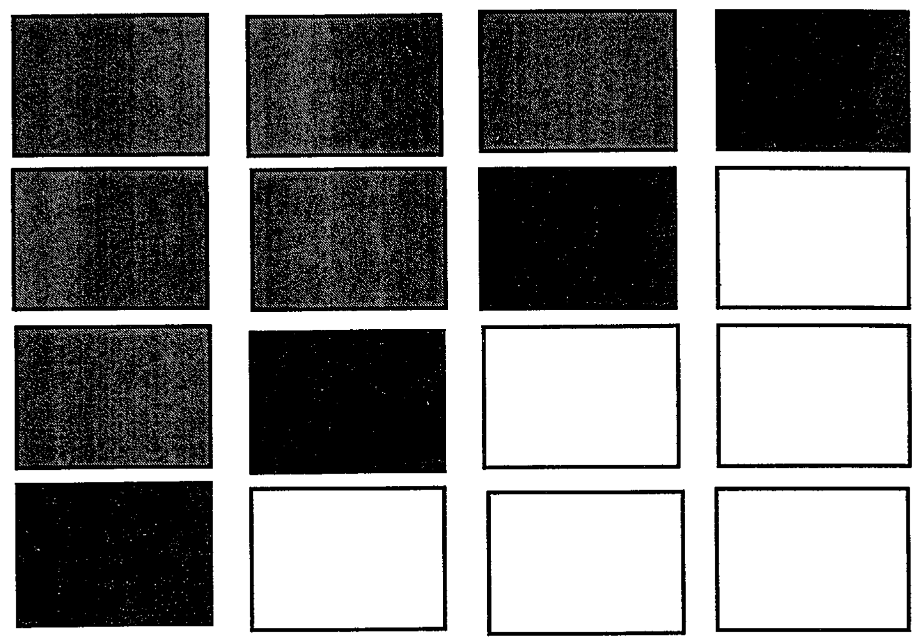


Figure 31 presents a hypothetical relationship between workload and operator performance. [19] Under low to moderate level of workload (region A), performance remains unchanged as workload increases. Under this region, it is assumed that the operator has sufficient spare resources to compensate for increases in level of load. Under Region B, higher levels of workload are experienced such that the operator can not compensate and performance degrades. Under extremely high levels of workload (Region C), the operator is unable to manage resources and performance tends to remain at a low level and unchanged. One of the primary reasons for employing workload measurement techniques is to measure reserve capacity under Region B as shown in figure 31.

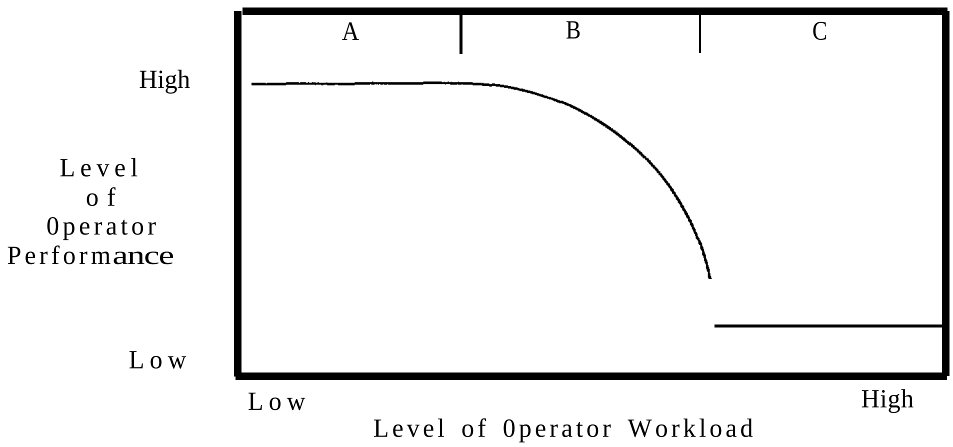


Figure 31. Hypothetical relationship between workload and operator performance. [19]

For the TravTek experiment, a rating scale with the following three dimensions was used: time stress; psychological stress; and effort (visual). The drivers rated workload on each of the above three dimensions with a 3-point rating scale (1 for low workload, and 3 for high workload). This type of scale represents a modification of the standard Subjective Workload Assessment Technique (SWAT). For SWAT, the raw ratings are converted to scaled scores using conjoint measurement.[19] However, in TravTek the raw rating of from 1 to 3 were used to analyze subjective workload. In addition, for the derivation of a global measure of workload, the ratings for the three separate dimension were added together. Therefore, the ratings for the individual dimensions ranged from 1 to 3, and for the global workload rating ranged from 3 (low) to 9 (high).

Subjective measures of workload are useful for discriminating levels of capacity expenditure in non-overload situations. They can be used to assess the relative potential for overload as a function of design options, tasks, or operating conditions. However, these techniques are not considered diagnostic. The available evidence suggests that rating scales represent a global measure of load. [19]

INDEPENDENT VARIABLES

The above types of variables were collected in the Field and System Effectiveness Studies. The independent variables of interest were:

1. Vehicle configuration
    a. Navigation Plus.
    b. Navigation.
    c. Services (or the control condition).

2. Display configuration
    a. Turn-by-Turn with Voice.
    b. Turn-by-Turn without Voice.
    c. Route Map with Voice.
    d. Route Map without Voice.
    e. Paper Map (Services or control only).

3. Level of Experience with TravTek System
    a. Low.
    b. Moderate to High.

4. Level of Experience with the Traffic Network (Orlando)
    a. Low(Visitors).
    b. High(Local high mileage driver).

5. Age
    a. 16-18.
    b. 35-45.
    c. Over 65.

6. Time of Day
    a. Day.
    b. Night.

Data for the dependent variables of interest were not available as a function of all of the above independent variables. There were six independent variables where all of variables were not crossed in a factorial manner. For example, display configuration can only be crossed with N and N+. The above list of independent variables and associated levels would yield a total of 216 conditions. The TravTek study did not support the generation of a matrix with 216 entries for all relevant safety variables.

The approach that was followed was to use available data at the level of resolution presented in the source document. This section presents an integrated discussion of safety-related measures across all of the studies.

For the purpose of discussion, the results of the studies are presented as a function of:

Vehicle Configuration Effects

Safety-related measures as function of the S (or control condition), N, and N+ are examined.

Display Configuration Effects

Data that pertains to the four different TravTek display combinations of visual display type (Turn-by-Turn or Route Map), and Voice display (with and without voice augmentation) are discussed. Also, the control condition of the Paper Map display condition is discussed.

Level of Experience with TravTek

Data pertaining to this effect comes from the Camera Car Study where local users were tested during the early portion of their TravTek usage and then again near the end. Results with respect to level of experience with the system are crossed with the type of display used in the experiment.

Level of Experience with the Orlando Traffic Network

Data for this effect come from the Camera Car Study where data were collected from local area residents and visitors. Results for this effect are also crossed with the type of display used in the experiment.

Age-Related Effects

Data for this effect come from the Camera Car Study where data were collected from drivers in the 35 to 45 year old category as well as drivers over 65. Results for this effect are also crossed with the type of display used in the experiment.

Time of Day Related Effects

Data with respect to time of day effects are only available from the OTNS.

VEHICLE CONFIGURATION EFFECTS

Close Calls from Observers

The Yoked Driver Study employed the N+, N, and S conditions with visitors to the Orlando area. The OTNS employed the N (with different display configurations), and a control condition. For the control condition the number of close calls per 1,610 veh-km (1,000 veh-mi) was 0.7053, and 0.5731 for the TravTek conditions (N and N+ combined). Though the close call rate was lower for the TravTek conditions, the difference between the rates are not statistically reliable.

Subjective Data

Subjective data are available from the Field and System Effectiveness Studies, based on questionnaire responses. Table 16 presents average responses for safety questions that were common to the **N+,** N, and S conditions. All of the averages are on a scale where 1 indicates poor safety and 6 indicates high safety. The data from the Rental User Study were used to derive the risk factor based on subjective questionnaire data. Data from the Local User Study did not include a control (non-TravTek condition). The data from the Yoked Driver Study were not used because the training procedure exposed all subjects to all conditions. Statistical analyses of the subjective ratings for the Yoked condition did not reveal statistically significant differences among the N+, N, and S Conditions. Overall, the ratings for the N and N+ conditions are about 20 percent more positive than the ratings for the S condition for safety-related questionnaire items. The drivers indicated that they perceived TravTek as safe.

Summary for Configuration Effects

For evaluating the relative safety of the N+ and N conditions the above represent the only available statistics. There were no safety-related performance measures (e.g., eye glance data) collected for these studies. The crash statistics (from the previous section) and the above results suggest that the TravTek configurations did not impose an additional safety risk relative to the Service condition. These data, in addition to the crash data presented earlier, further indicate that TravTek did not impose an added safety risk.

Answers to all of the safety-related questions show that drivers perceived that the TravTek system, either N+ or N, was between 0.2 and 1.6 points higher (on a 6-point scale) than the Service condition. This statistically significant difference in perception of safety was supported by a 19 percent reduction in the number of observer reported close calls (OTNS and Yoked studies).

Table 16. Subjective responses for safety-related questionnaire items.

Measures	Rental User Study		
	N+	N	Serv
Subjective Measures	Mean	Mean	Mean
T.T. Help Drive More Safely	4.11	3.98	2.40
T.T. Changed attention to:			
Traffic & Other Drivers	3.82	3.77	3.64
Road Signs	2.71	2.61	2.26
Billboards	2.91	2.84	2.64
Paper Road Maps	4.32	4.19	2.72
Street Signs	3.04	2.89	2.34
Freq of Close Calls	4.74	4.74	4.81
T.T. Helped Pay Attention	4.22	4.28	3.12
T.T. Interfered	4.40	4.38	4.73
Average	3.81	3.74	3.18
Ratio Cond/Serv	120%	118%	100%

DISPLAY CONFIGURATION EFFECTS

Several issues need to be considered now as well as for the rest of the discussion in this section. In the Camera Car Study and OTNS, the drivers were required to use a given configuration of the TravTek displays. The system was designed so that drivers would use the simplified Turn-by-Turn display as a default when following route directions. This display, at the driver's command, could be augmented with voice directions. Also, the Route Map display could be commanded by the driver and swapped for the Turn-by-Turn display. Thus the system, as designed, provided the driver flexibility for obtaining needed information. The system was not designed for drivers to exclusively use the Route Map without voice augmentation for following route directions.

The use of close call or safety error data tends to understate the potential safety impact of using Paper Map directions versus some other navigation aid. First, the drivers in this condition selected a route from a Paper Map and then listed a series of turn instructions on a piece of paper. The drivers knew the route that they were to take and tended to follow a memorized set of turn directions. Second, when these drivers needed routing information, they tended to stop the vehicle to consult the map or directions. These factors tend to underestimate the actual safety risk associated with the non-electronic navigation aids.

The OTNS and Camera Car Studies evaluated safety measures under different display configurations. These included:

Turn-by-Turn with Voice (OTNS & Camera Car).
Turn-by-Turn with no Voice (OTNS & Camera Car).
Route Map with Voice (OTNS & Camera Car).
Route Map with no Voice (OTNS & Camera Car).
Voice Only (OTNS).
Paper Directions (Camera Car).
Paper Map (Camera Car).
Paper Map/ Directions from Help Desk (OTNS).

Close Call Data

Risk Assessment Variable (Undesirable Risk)

The count of Undesirable Risk for the navigation display conditions are presented in table 17. The table also presents "proportion Change/Control." This is the proportion computed by dividing the raw score for the TravTek display condition by the raw score from the Paper Map condition. This approach is used for all of the tables that follow.

Table 17. Count of undesirable risk. (18)

Condition	Raw Score	Proportion Change/Control
TT with Voice	40	1.333
TT without Voice	57	1.900
RM with Voice	38	1.267
RM without Voice	77	2.567
Paper Map	30	1 .000

The statistics in the above table indicate that the TravTek conditions are higher in risk relative to the control (Paper Map). The display conditions that employed voice augmentation, were the TravTek conditions with the lowest risk Overall, the voice augmentation tended to increase the safety of the TravTek visual displays.

Number of Safety-Related Errors Caused by a Glance at the Navigation Display (Hazard Present)

The number of safety-related errors counted from the recorded roadway video were classified in terms of the presence of roadway hazards. Table 18 presents a count of these safety-related errors as a function of navigation display. As may be expected, these results are consistent with those shown in the previous table. The Route-Map display was shown to lead to the largest number of safety-related errors for the TravTek conditions. The Paper Map condition was shown to result in the fewest safety-related errors for the conditions tested. Again, the Paper Map condition appears to be one in which drivers follow a memorized route, and when they need additional routing information they stopped the vehicle to consult the map or paper directions.

Table 18. Count of safety-related error when a hazard was present. (18)

Condition	Raw Score	Proportion Change/Control
.TT with Voice	30	1.580
TT without Voice	52	2.740
RM with Voice	40	2.110
RM without	102	5.375
Paper Man	19	1 .000

Safety-Related Errors (Total)

Total safety-related errors were computed from the roadway video. Again, this total count of close calls shows a pattern similar to that observed for the previous two tables.

Table 19. Count of total safety-related errors. (18)

Condition	Raw Score	Proportion Change/Control
TT with Voice	62	1.550
TT without Voice	82	2.050
RM with Voice	65	1.625
RM without	130	3.250
Paper Man	40	1 .000

Performance Data

Number of Unplanned Lane Deviations

As reported in the Camera Car report, the overall average duration for a lane deviation during the study was 3.86 s. [18] There were no significant differences between lane deviation duration for the navigation conditions. Table 20 shows a count of unplanned lane deviations for glances to the navigation aids. This result further illustrates that the Route Map display without voice appears to have presented the highest level of risk of the options tested.

Table 20. Number of unplanned lane deviation maneuvers . [18]

Condition	Raw Score	Proportion Change/Control
TT with Voice	13	0.500
TT without Voice	15	0.577
RM with Voice	15	0.577
RM without	34	1.308
Paper Map	26	1.000

Number of Abrupt Longitudinal Acceleration Maneuvers

This measure was presented in the Camera Car Study report and summary statistics are presented in table 21. An abrupt maneuver was defined in terms of exceeding the first percentile negative longitudinal acceleration value for all of the data. [18] The results showed that drivers in the Paper Map condition made the greatest number of abrupt maneuvers. Based on other results from the Camera Car Study, this appears to reflect the greater number of stops made in the Paper Map condition. Drivers in this condition often slowed down to turn into a parking lot to study the map, and in the process performed more abrupt maneuvers.

Table 21. Frequency of abrupt longitudinal acceleration maneuvers. [18]

Condition	Raw Score	Proportion Change/Control
TT with Voice	17	0.680
TT without Voice	17	0.680
RM with Voice	18	0.720
RM without	20	0.800
Paper Map	25	1 .000

Number of Eye Glances > 2.5 s Away from the Roadway

In the Camera Car Study, frequency of eye glances greater than 2.5 s away from the roadway were computed and are shown in table 22. This threshold was based on previous research that indicates that any single display glance greater than 2.5 s is inherently dangerous. [20] This statistic shows the greatest potential safety risk for the Route Map Display without voice. The Turn-by-Turn display with voice was the least risky of the TravTek conditions.

Table 22. Number of eye glances away from the roadway greater than 2.5 s. (18)

Condition	Raw Score	Proportion Change/Control
TT with Voice	17	1.417
TT without Voice	59	4.917
RM with Voice	48	4.000
RM without	114	9.500
Paper Map	12	1.000

Total Workload

Workload was measured in the Camera Car Study by having drivers rate their perceived workload on a scale from 1 (low) to 3 (high) as a function of time stress, psychological stress, and visual effort.(18) The workload rating were collected periodically throughout the study. Table 23 presents total workload collapsed over the above three dimensions. These workload rating simply represent the sum of the three rating for each subject averaged over all subjects as a function of the navigation conditions. The table shows that subjects perceived the Paper Map condition as presenting the highest workload. Also, the Route Map display without voice was rated as the highest workload TravTek display condition. The other TravTek display conditions were rated lowest in workload.

Table 23. Average ratings of total reported workload.

Condition	Raw Score	Proportion Change/Control
TT with Voice	3.65	0.730
TT without Voice	3.70	0.740
RM with Voice	3.70	0.740
RM without	4.65	0.930
Paper Map	5.00	1 .000

Summary of Display Configuration Effects

Measures of safety-related errors showed best performance for the TravTek Turn-by-Turn display. The low frequency of safety-related errors for the Paper Map condition appears to be attributed to the fact that these drivers where following a memorized route and stopped the vehicle when they needed route guidance information. This stopping behavior for the drivers in the Paper Map condition was reflected in the performance measures. Additional discussion of the safety implications of alternative in-vehicle display configurations can be found in the Camera Car Study report. (18) Further discussion of the configuration effects on safety, as presented here, are included in the summary for this section of the report.

LEVEL OF EXPERIENCE WITH TRAVTEK

Close Call Data

Number of Safety-Related Errors (Total)

The total number of safety-related errors .was tabulated as a function of Local Driver first and second drive, and navigation display configuration. This is the same measure that was discussed earlier for total number of safety-related errors as a function of navigation display conditions. Table 24 presents the results as a function of first and second drive versus display condition. The table presents frequencies as well as relative change within each cell entry with respect to the Paper Map/First Drive. First drive is used as the baseline condition for this analyses. The table shows large effects in terms of reduction in safety errors for first versus second drive. The Route Map conditions showed the largest decrease as a function of experience with the TravTek system.

Table 24. Total number of safety-related-errors. (18)

Condition	TT Voice	TT no Voice	RM Voice	RMno Voice	Paper
Local 1st Drive	57/l .036	70/l ,273	75/l .364	100/1.818	55/l .00
Local 2nd Drive	44/0.800	4510.818	24/0.436	55/l .000	20/0.364

Performance Data

Number of Unplanned Lane Deviations

The number of unplanned deviations were computed from the roadway video in the Camera Car Study. Unplanned lane deviations is a face valid indicator of driver inattention and collision potential. (18) Table 25 presents summary results for lane deviations. The Route Map display without voice appears to have the highest risk potential. However, by the second drive, performance across all TravTek conditions was nearly equivalent.

Table 25. Number of unplanned lane deviations. (18)

Condition	TT Voice	TT no Voice	RM Voice	RMno Voice	Paper
Local 1st Drive	16/l .78	15/l .67	22/2.44	10/.11	9/l.00
Local 2nd Drive	9/l.00	1 l/l .22	1 l/1.22	1l/l .22	410.44

Number of Eye Glances Greater than 2.5 s Away from the Roadway

Number of eye glances greater than 2.5 s away from the roadway were computed as a function of driver experience with the TravTek system and display configuration. This is the same measure that was discussed earlier with respect to display configuration effects. As shown in table 26, the Turn-by-Turn display with voice showed the lowest risk for the TravTek displays and the Route Map without voice the highest. There was a large drop (improvement) in this measure for all conditions as a function of the second drive; however, the Route Map without voice was still approximately 4 times higher than the Paper Map condition for the second drive.

Table 26. Number of eye glances greater than 2.5 s as a function of experience with TravTek and display configurations. (18)

Condition	TT Voice	TT no Voice	RM Voice	RMno Voice	Paper
Local 1st Drive	12/l .50	3914.88	40/5.00	85/10.63	8/l .OO
Local 2nd Drive	5/0.63	20/2.50	8/l .OO	2913.63	4/0.50

Workload Data

Workload as a function of experience with TravTek and navigation display configurations is presented in table 27. This metric was computed as discussed earlier. As was shown earlier the Paper Map condition resulted in the highest ratings of perceived workload with the Route Map without voice receiving the second highest rating of workload. The table also shows that perceived workload was relatively unchanged with experience with TravTek except for the Paper Map condition. In the Paper Map condition the drivers gave a higher rating of workload for their second drive relative to the first.

Table 27. Average workload as a function of experience with TravTek and navigation display configurations.(18)

Condition	TT Voice	TT no Voice	RM Voice	RMno Voice	Paper
Local 1st Drive	3.610.86	3.8/0.90	3.6/0.86	4.6/1.09	4.2/1 .OO
Local 2nd Drive	3.6/0.86	3.8/0.90	3.5/0.83	4.7/1.12	5.1/1.21

Summary of Level of Experience with TravTek Factor

Experience with the TravTek system had large effects on safety-related errors and eye glance behavior. These changes were most noticeable in the Route Map without voice condition which was uniformly rated as the highest workload display configuration.

LEVEL OF EXPERIENCE WITH THE ORLANDO TRAFFIC NETWORK

Close Call Data

Safety-Related Errors (Total)

Total safety-related errors as a function of Local drivers versus Renters was computed in the Camera Car Study. There were a total of 192 safety-related errors for the Locals and 120 for the Renters. This single result suggests that the Renters may have been more cautious in driving the TravTek vehicles relative to the Locals.

Performance Data

Number of Lane Deviations

The number of lane deviations as a function of experience with the Orlando traffic network and display configuration are presented in table 28. This is the same statistic that was discussed earlier with respect to unplanned lane deviations. The data from the Visitors is consistent with earlier results showing the Turn-by-Turn with voice as the lowest risk condition. However, for the Locals Paper Map and the Route Map without voice appear to present the lowest risk for this measure.

Table 28. Number of lane deviations as a function of experience with the Orlando traffic network and display configuration. [18]

Condition	TT Voice	TT no Voice	RM Voice	RMno Voice	Paper
Local 1st Drive	16/2.00	14/.75	22/2.75	9/1.13	8/1 .OO
Visitor	4/0.50	3/0.38	7/0.88	10/1.25	15/1.88

Average Duration of Glances (in seconds) to Navigation Display

The average duration of eye glances to the navigation displays was computed in the Camera Car Study. Table 29 presents this statistic as a function of navigation display configuration and experience with the Orlando traffic network. This statistic is indicative of the visual workload associated with each display and may be correlated to risk (e.g., in a similar manner as eye glances greater than 2.5 s away from the roadway). The table shows equal performance for the Locals and Visitors for the Paper Map display. For the other conditions, the Visitors show slightly lower averages relative to the Locals.

Table 29. Average duration of glances (in seconds) to navigation displays. [18]

Condition	TT Voice	TT no Voice	RM Voice	RM no Voice	Paper
Local 1st Drive	0.98/0.93	1.05/l .00	1.1/1.05	1.2/1.14	1.05/l .00
Visitor	0.97/0.92	0.98/0.93	1.05/l .00	1.3/l .24	1.05/l .00

Summary of Level of Experience with the Orlando Traffic Network Factor

The results suggest that Visitors may have been more cautious than the Locals when driving TravTek vehicles. For the lane deviation measure, counterintuitive results were found for the Locals where the Paper Map condition resulted in the fewest number of lane deviations.

AGE EFFECTS

Close Call Data

Number of Safety-Related Errors (Total)

The total number of safety-related errors were computed for the 35-45 year old group (121 safety errors), and the 65 and older group (173 safety errors) in the Camera Car Study. the older drivers showed riskier performance relative to the younger drivers.

Performance Data

Number of Glances Greater than 2.5 s Away from the Roadway

Number of eye glances greater than 2.5 s were computed as a function of age group and navigation display condition. Table 30 shows the summary statistics for this analyses. The table presents frequencies as well as relative change within each cell entry with respect to the Paper Map/35-40. First drive is used as the baseline condition for this analyses. The younger and older drivers showed a similar trend with respect to eye glance performance. The Turn-by-Turn display with voice showed the best performance relative to the Paper Map condition. Also, the Route Map without voice condition was shown to lead to worst performance.

Table 30. Number of eye glances greater than 2.5 s as a function of display condition and driver age. (18)

Condition	TT Voice	TT no Voice	RM Voice	RMno Voice	Paper
35-45	210.50	1012.50	912.25	2115.25	4/l .00
65>	7/l .75	1914.75	1814.50	3518.75	1012.50

Number of Lane Deviations

Over all there were very few unplanned lane deviations as a function of driver age and display conditions. As shown in table 3 1, the younger drivers had fewer lane deviations relative to the older driver. Of more interest is the fact that the older drivers had fewer lane deviations in the TravTek conditions relative to the Paper Map. Also, the fewest number of lane deviations were observed for the Turn-by-Turn display condition.

Table 3 1. Number of lane deviations as a function of driver age and display configuration. (18)

Condition	TT Voice	TT no Voice	RM Voice	RM no Voice	Paper
35-45	210.67	110.33	210.67	3/l.00	3/l.00
65>	210.67	210.67	5/l .67	812.67	1314.33

Summary of Age Effects

The findings for age effects are consistent with previous highway safety research. Generally, the older drivers showed riskier performance relative to the younger drivers. Of note is the finding that with the Turn-by-Turn display with voice, the older drivers performed nearly the same as the younger drivers.

TIME OF DAY EFFECTS

Data on time of day effects are only available from the OTNS For this study there were no performance measures related to safety. Close call were collected from an in-vehicle observer. However there were only a total of 11 close call for this study, and further analyses that would require breaking this small number into 10 different cells does not appear warranted. Therefore, the only available statistics for this factor are the workload ratings.

Workload Data

Workload rating were collected in the OTNS in similar fashion as in the Camera Car Study. For the purpose of this analyses, the workload ratings for visual effort are the only ones employed since time and mental effort rating were not statistically reliable. Table 32 presents the results in terms of time of day and display configurations for workload. The table presents frequencies as well as relative change within each cell entry with respect to the Paper Map/Day. First drive is used as the baseline condition for this analyses. The basic result is that workload was higher in the Paper Map condition relative to the TravTek conditions. The differences in ratings between the day and night conditions were not reliable.

Table 32. Workload ratings as a function of time of day and display configurations [TravTek OTNS].

Condition	TT Voice	TT no Voice	RM Voice	RM no Voice	Paper
Day	1.146/0.87	1.113/0.85	1.168/0.89	1.229/0.94	1.311/1.00
Night	1.181/0.90	1.186/0.90	1.208/0.92	1.244/0.95	1.437/1.10

Summary of Time of Day Effects

There was not sufficient data available to explore the effect of time of day on safety-related measures. The workload data shows slight increases in visual workload for the night-time condition relative to day.

SUMMARY

Estimates of safety risk were addressed by analyzing near misses and other safety-related errors. A systematic method of classification was developed as a means of assessing the severity of safety-related errors. Events were classified by the “environmental proximity” of a hazard to the camera car. The environmental proximity for each error was placed into one of three categories: near miss, driver error hazard present, and driver error no hazard present.

Two measures of performance that are indicative of the relative level of safety are the number of near misses and the number of safety-related errors when a hazard was present. Analysis of the data for near misses shows that when driving with the Route Map, either with or without voice augmentation, drivers had about twice as many near misses as in the other configurations. It should be kept in mind that drivers in the Paper Map condition were apparently navigating more from memory than in the other conditions and that they were instructed to stop if they needed additional information when in this condition. Data for the second measure, safety-related errors when a hazard was present, shows a similar trend. Again, drivers had the lowest score for this measure when using the Paper Map (with memorized route) and the highest number of errors when using the Route Map without voice augmentation. From the analysis of these two measures, the TravTek Turn-by-Turn display with voice augmentation appears to impose a level of safety-related distraction which is about the same level as experienced when driving a memorized route. The other TravTek configurations, except for the Route Map without voice augmentation, appear to produce intermediate levels of safety-related events, and the Route Map without voice appears to significantly more safety-related errors and near misses than any of the other configurations. Individual safety-related measures, such as lane deviations, glance duration's in excess of 2.5 s, and abrupt longitudinal maneuvers showed similar patterns: Turn-by-Turn with voice among the best and Route Map without voice consistently being the worst on all measures.

It should be noted that the drivers in the Rental User and Local User Studies, who were free to choose what display to present for route guidance information, tended to select the Turn-by-Turn display with voice augmentation most frequently. (21) When drivers were free to choose the specific display configuration to use, they tended to select the default and safer configuration.

The results presented in this section and those by Perez et al. showed that drivers rated the TravTek system (N+ and N) significantly higher than the S condition with respect to such factors as; utility (e.g., saving time, avoiding congestion, helping to locate destinations, and helping to reach destinations), safety, and the enhancement of mobility. (22) In addition, the report by Van Aerde and Rakha, showed that the TravTek conditions resulted in fewer wrong turns (navigational errors), and shorter travel times relative to the control conditions. (3)

Though issues with respect to mobility and other traveler benefits may not be considered part of a safety evaluation, these factors should be considered in any comprehensive safety evaluation of a ATIS. An effective ATIS implementation should provide drivers benefits with respect to mobility and reduction in wasted travel (e.g., reduction in navigation errors), while at the same time not degrading or preferably enhancing safety. Thus far this report has shown that drivers of the TravTek system, when using a Turn-by-Turn display with voice augmentation for route guidance, experienced a level of safety comparable to drivers following a memorized route in the control (non-TravTek) conditions. In addition, the TravTek drivers experienced significant traveler benefits when compared to drivers of non-TravTek vehicles.

MODELING THE POTENTIAL SAFETY IMPACT OF TRAVTEK

The third objective of the Safety Study was to estimate the potential safety impacts of a TravTek-like system at different levels of market penetration. Estimation of the safety impacts was accomplished through use of the INTEGRATION model. The use of the INTEGRATION model allowed the evaluation of multiple variables that could affect safety in a dynamic and integrated fashion. Thus far this paper has considered the impact of such factors as the road class driven, level of congestion experienced, and different TravTek configurations on safety. However, these factors have been considered in isolation where potential trade-off among variables has not been examined.

The TravTek system presents the capability of affecting safety through reduction in navigational waste, congestion avoidance, and the interactions of the driver with the in-vehicle system. The determination of the impacts of congestion and road class were described previously in this report and the derived factors were included in the INTEGRATION model. The model also includes the vehicle routing logic and driver performance with respect to wrong turn behavior. (3) The impact of TravTek and the different in-vehicle configurations on safety have been examined; however, for the purpose of modeling studies these effects need to be quantified. The following presents: (1) the methods and results used for integrating safety data across the TravTek empirical studies; and (2) the results of INTEGRATION modeling runs.

SAFETY DATA THAT WERE COLLECTED

The types of data that were collected for the Safety Study are summarized in tables 33 and 34. Table 33 lists those variables utilized in the NAV/Nav Plus/Services comparison, while table 34 lists those variables utilized in the Turn-by-Turn, Route Map and Voice configuration comparisons. The measures presented in these tables were discussed in detail in the previous section of this report.

It can be noted that for each data type, a reference to a document which provides a more detailed description of each experiment is presented. This reference is provided as it would be somewhat redundant to fully describe here each experimental design at the same level of detail as the reports dealings specifically with these experiments. Also noted, for each data source, is an identification of the type of experiment that data were collected from (e.g., Yoked or Camera Car Study).

Table 33. Variables utilized to compare Nav Plus, Nav, and Services conditions.

Measures	Source
Crashes	TravTek Rental User Study (23)
Safety Errors	Camera Car Study (18)
Questionnaire	Rental User Questionnaire Summary Report
Observer Reported Close Calls	Yoked & OTNS Studies (21)
Abrupt Stops (Yoked)	Yoked Study (3)

Table 34. Variables utilized to compare Turn-by-Turn, Route Map, and Voice augmentation.

Measures	**Source**
Crashes	TravTek Rental User Study[23]
Risk Assessment Measure	Camera Car Study [18]
Safety-Related Errors	Camera Car Study [18]
Lane Deviation (for Nav display glances only)	Camera Car Study [18]
Longitudinal Acceleration Maneuvers	Camera Car Study [18]
Eye Glances > 2.5 s	Camera Car Study [18]
Workload	Camera Car Study [18] , Yoked Driver Study, OTNS

The assessment of the safety implications of the TravTek system and alternative in-vehicle display configurations (e.g., Route Map display with voice augmentation) were discussed in the previous sections of this report. The assessment entailed an examination of crashes, performance data, in-vehicle observer records, transcribed video recorded data, workload ratings, and driver ratings of safety. The most insight regarding the potential safety impact of a TravTek-like system was derived from the safety-related measures (e.g., performance, workload, driver ratings) rather than the available crash data.

In order to conduct modeling studies that included the potential safety impact of TravTek configurations and other independent variables of interest, the above set of measures need to be: (1) converted to units that represent safety risk; and (2) combined to generate composite safety risk scores. These requirement present theoretical and analytical challenges which are discussed below.

The different safety-related measures have varying degrees of relationship to the construct of safety. For example, measures of visual attention such as **the number of eye glances greater than 2.5 s away from the roadway,** appear to be valid measures of safety risk. [18] On the other hand, measures of driver workload appear to be global measures of load and are not as directly related to safety risk. Presently there no well established rank orderings of the multitude of available safety-related measures with respect to their relationship to safety risk. The report by Green presents a review of measures usable to evaluate the safety implications of driver information systems. [24] The measures listed as the most promising for safety and usability testing were; the standard deviation of lane position, speed, speed variance, and the mean and frequency of driver eye fixations to displays and mirrors. [24] This report indicates that subjective and physiologically based measures are weaker predictors of usability and safety than the above mentioned performance based measures.

Another issue to consider in the use of safety-related measures, is the way in which they should be combined to derive a comprehensive assessment of safety risk. Figure 32 presents number of incidents and driving time as a function of alternative TravTek configurations. [23] If we were to only consider the number of incidents observed, the conclusion might be drawn that in-vehicle displays are categorically less safe than Paper Map directions for the task of route following. However, the drive time data indicates that drivers using TravTek in-vehicle displays reached their destinations significantly faster than those using Paper Map directions. Further evaluation of the results indicates that drivers using Paper Maps tended to follow memorized routes and when they needed additional routing information, they stopped their vehicle to examine the Paper Map.

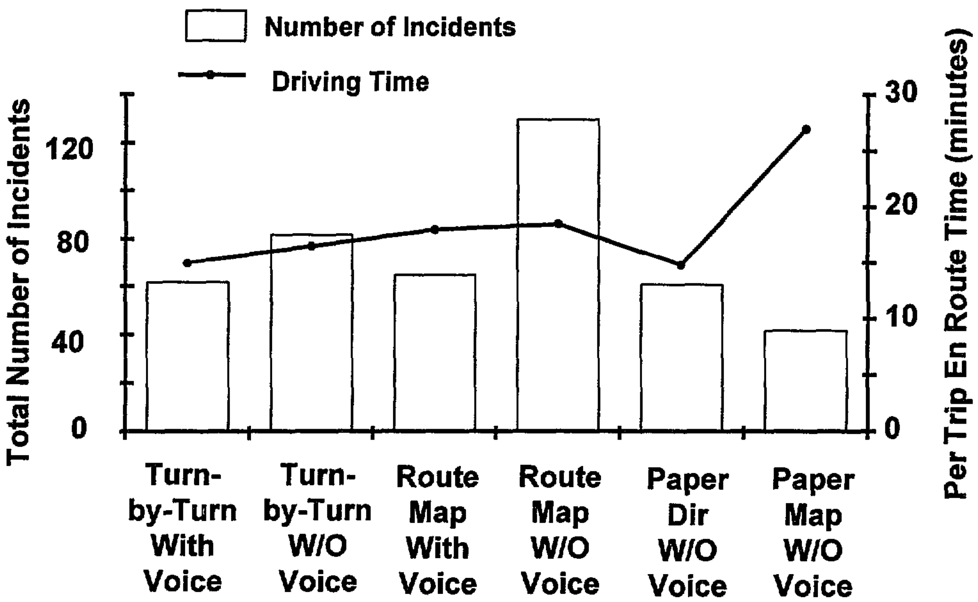


Figure 32. Number of incidents and driving time as a function of TravTek display configuration. (23)

As the above illustration indicates, the safety assessment of driver information systems needs include the collection of multiple performance measures. The use of a single or a limited number of measures may lead to a completely erroneous conclusion.

The current state of the art for safety-related measures does present a means by which to: (1) weight each separate measure with respect to its ability to predict safety; (2) convert the all the different measures into a common scale (that reflects safety risk); and (3) a means to generate integrated risk scores. The following section of the report presents the methodology that used to generate integrated risk scores to support INTEGRATION modeling studies. The methods used in this report require additional empirical calibration and validation; however, they do present a logical and traceable means by which to obtain the required metrics.

INTEGRATION OF EMPIRICAL RESULTS

Figure 33 presents an overview of the overall method used to derive the final Integrated Risk Factors (IRF) for the TravTek study. The method entails four major steps: (1) Transformation of the selected Raw Risk Scores (RRS) into a common Transformed Risk Score (TRS); (2)

Normalization of the Transformed Risk Scores into Normalized Risk Scores (NRS); (3) Computation of Component Risk Factors (CRF) for each individual factor from the Normalized Risk Scores; and (4) Computation of the combined Integrated Risk Factors (IRF) from the Component Risk Factors. (Appendix B presents more-detailed examples of the computational procedures used in the data fusion process.)

The first step in this process was the derivation of translation functions that converted the various safety-related measures into a common metric. The approach employed subject matter experts to derive the functions. The subject matter experts were presented three data points for each performance metric which they rated with respect to risk. Figure 34 presents results for the lane deviation measure. The translation function for this measure is a quadratic function of the form shown in Equation 1. Quadratic functions were derived for all of the safety-related measures described earlier.

$$TRS = a + bxRRS + cXRRS^2 \qquad (1)$$

In addition to providing ratings of risk for the safety-related measures, the subject matter experts provided weights for each measure. The weights represented the subject matter expert's opinions regarding the relationship between a given measure and safety. For example, weights were provided for close calls, lane deviations, workload ratings, subjective measures, etc.

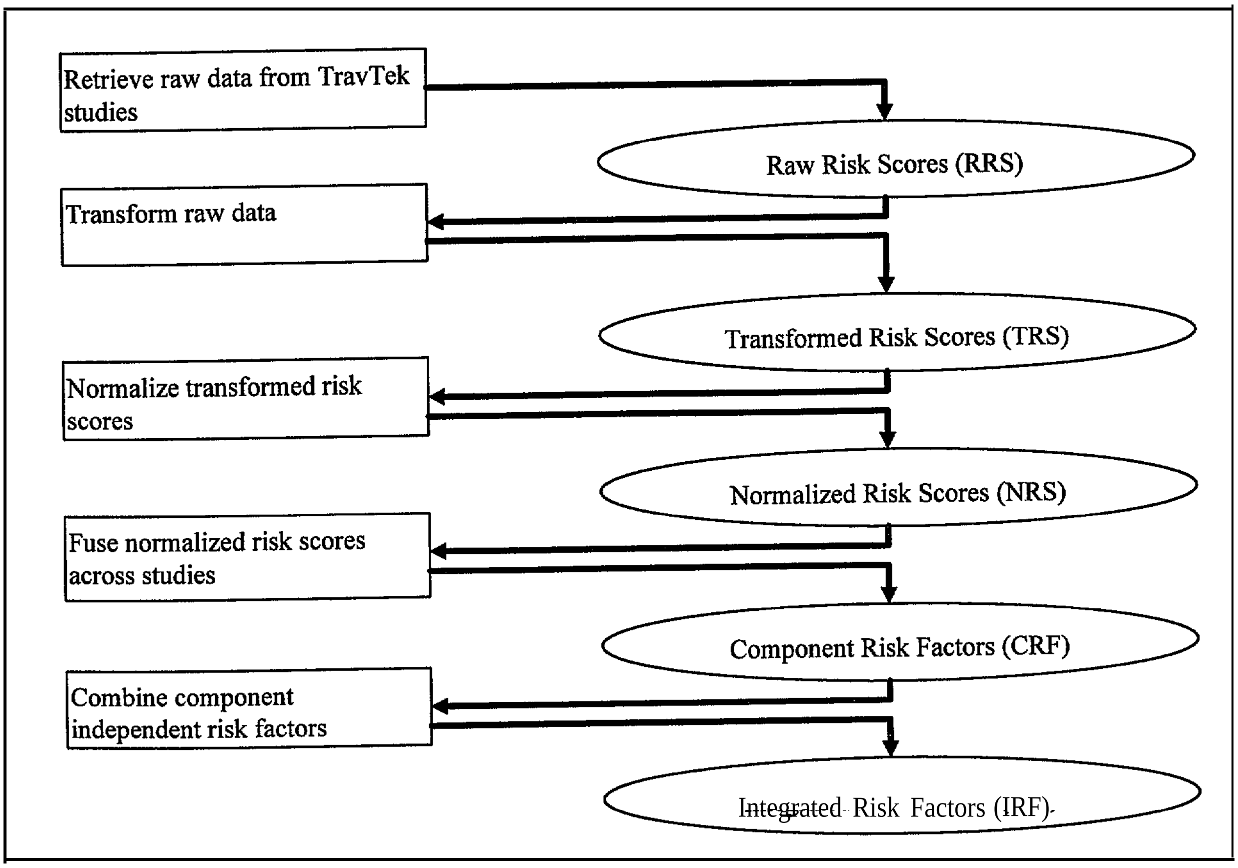


Figure 33. Methodology for derivation of integrated risk factors.

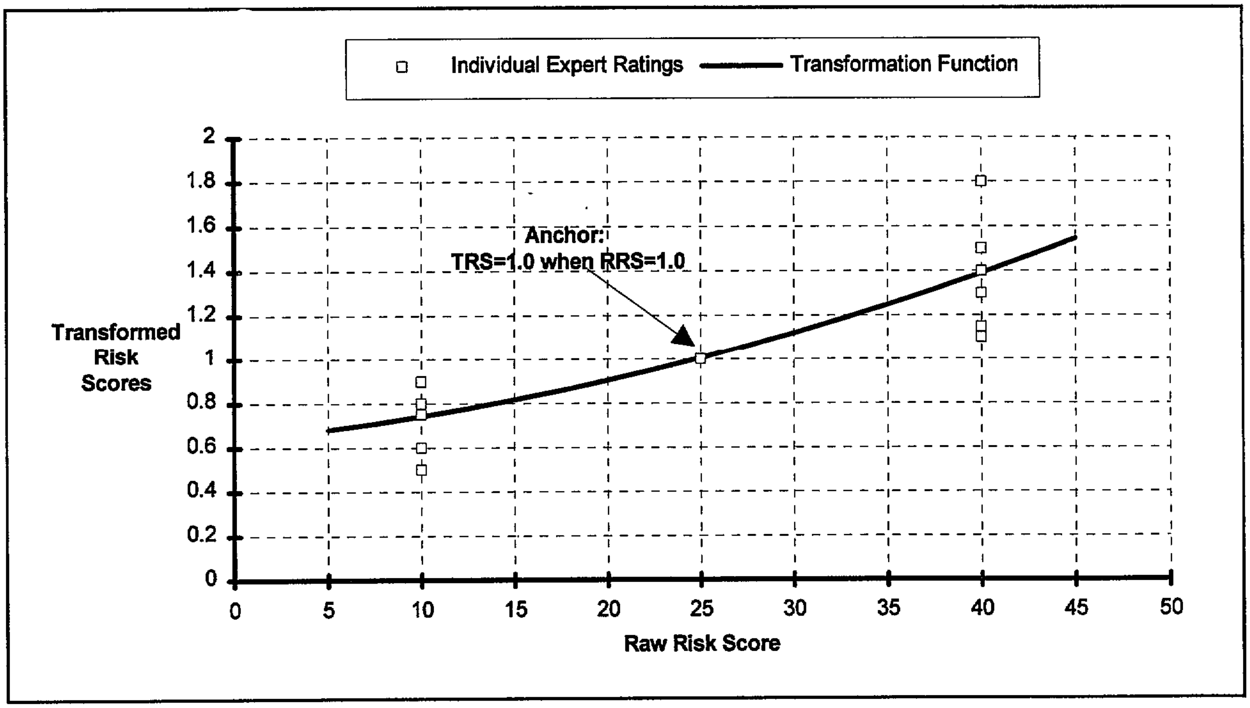


Figure 34. Illustration of calibration of transformation function for lane deviations.

Table 35 presents an example set of transformations for performance variables as a function of display configuration. The table shows raw scores, transformed risk scores, and normalized risk scores. The normalized risk scores were derived by dividing the *TRS* for the TravTek conditions by the corresponding control condition scores.

Table 35. Sample results of transformation and normalization of raw risk scores.

		Raw Risk Scores				Transformed Risk Scores				Normalized Risk Scores		
		Lane Dev.	Long. Acc.	Eye Glance		Lane Dev.	Long. Acc.	Eye Glance		Lane Dev.	Long. Acc.	Eye Glance
Turn-by-Turn	Voice	13	17	17		0.790	0.943	0.700		0.754	0.813	1.030
	No Voice	15	17	59		0.823	0.943	0.873		0.786	0.813	1.283
Route Map	Voice	15	18	48		0.823	0.965	0.827		0.786	0.832	1.217
	No Voice	34	20	114		1.257	1.014	1.096		1.189	0.874	1.615
Paper Map	-	26	25	12		1.048	1.180	0.880		1.000	1.000	1.000

In order to combine the diverse sources of data, equation 2 was employed to establish weighted geometric or multiplicative averages.

$$CRF = \prod \left(NRS_i^{w_{NRS_i}} \right) \qquad (2)$$

where: $\sum \left(w_{NRS_i} \right) = 1.0$

Table 36 presents an example application of equation 2 for three performance metrics as a function of display configuration.

Table 36. Sample calculations of data fusion of different data sources.

		Lane deviation Nav display (Camera)	Longitudinal acceleration (Camera)	Eye glance > 2.5 s (Camera)	Combined Component Risk Factor
		0.41	0.24	0.35	
Turn-by-Turn	Voice	0.754	0.813	1.030	0.857
	No voice	0.786	0.813	1.283	0.942
Route Map	Voice	0.786	0.832	1.217	0.929
	No voice	1.199	0.874	1.615	1.236
Paper Map		1.000	1.000	1.000	1.000

Table 37 presents a summary of the results achieved for all of the independent variables of interest. It should be noted that the TravTek operational test did not include all of the variables listed in table 37 in a factorial manner. In other words, none of the experiments included the crossing of all of the seven variables (experience with system, local versus visitor, age, time of day, Route Map versus Turn-by-Turn, voice guidance on or off, and navigation versus navigation plus) listed in table 37. What were available were main effects and first order interactions. Also, safety-related measures were not collected as a function of all interactions present in table 37. The computation of the risk scores shown in table 37 entailed a cross multiplication of available results where the variables were not assumed to significantly interact (beyond first order interactions).

A scan of the first column in table 37 indicates that the N+ vehicle with a Turn-by-Turn display and the Voice active was always superior, in terms of safety, to the services condition as all relative Integrated Risk Factors in column 1 are less than 1.000. From column 2 it can be noted that a N+ vehicle with a Turn-by-Turn display but without voice represents a slightly higher risk for 2 environmental conditions associated with younger Local drivers on their First Drive (1 .010 and 1.008), but that for all other conditions the relative Integrated Risk Factors are again less than 1.000. As subsequent columns are scanned for the Route Map display and for the N condition, it can be noted that increasingly a larger number of the environmental conditions result in relative risks which are slightly larger than the corresponding risks for the Services condition. For example, for the N condition with a Route Map display and No voice, 10 of the 18 environmental conditions resulted in relative risks greater than the comparable Services condition. However, it should be noted that even the least safe condition was only less than 9 percent more risky than the comparable Services condition.

Table 37. Summary of final integrated risk factors (absolute values).

				N+				Nav				Services
				TT		RM		TT		RM		
				Voice	NoVoice	Voice	No Voice	Voice	No Voice	Voice	No Voice	
1st	Local	35-45	Day	0.972	1.010	1.035	1.070	0.989	1.027	1.052	1.088	1.000
			Night	0.968	1.008	1.031	1.065	0.985	1.024	1.048	1.083	1.000
		>65	Day	0.955	0.995	1.023	1.064	0.971	1.012	1.040	1.082	1.000
			Night	0.951	0.993	1.019	1.059	0.967	1.009	1.036	1.077	1.000
	Visitor	35-45	Day	0.937	0.971	0.986	1.068	0.953	0.987	1.002	1.086	1.000
			Night	0.933	0.968	0.982	1.062	0.949	0.985	0.998	1.080	1.000
		>65	Day	0.920	0.956	0.975	1.062	0.935	0.972	0.991	1.080	1.000
			Night	0.916	0.954	0.971	1.056	0.932	0.970	0.987	1.074	1.000
2nd	Local	35-45	Day	0.974	0.987	0.948	0.987	0.990	1.003	0.964	1.003	1.000
			Night	0.970	0.985	0.944	0.982	0.986	1.001	0.960	0.998	1.000
		>65	Day	0.956	0.972	0.937	0.981	0.972	0.989	0.949	0.993	1.000
			Night	0.952	0.970	0.933	0.976	0.968	0.986	0.949	0.993	1.000
	Visitor	35-45	Day	0.939	0.949	0.903	0.984	0.954	0.964	0.918	1.001	1.000
			Night	0.935	0.946	0.899	0.979	0.950	0.962	0.914	0.996	1.000
		>65	Day	0.921	0.935	0.892	0.979	0.937	0.950	0.907	0.995	1.000
			Night	0.918	0.932	0.889	0.974	0.933	0.948	0.904	0.990	1.000

MODELING EXPERIMENT

The previous sections of this paper have indicated that the safety impact of utilizing a TravTek type of system depends heavily on 4 main factors, namely the configuration of the particular TravTek device, the distance driven with the vehicle, the type of road the vehicle is driven on, and the level of congestion experienced. The difficulty in making an overall assessment of the safety impact of the TravTek system arises from the fact that the impact of these factors are highly dependent upon the network topography, the networks traffic characteristics, and percentage of drivers who are concurrently utilizing TravTek on the network. The complexities of the above interactions, as well as the associated temporal dynamics, preclude a simple analytical approach, especially if trade-off of accident risk versus trip efficiency were to be made.

The INTEGRATION simulation model's traffic flow, assignment, and ITS features are already well established in terms of their ability to objectively represent the traffic and environmental features of a traffic network. It was therefore convenient to utilize the same model, and therefore many of the same assumptions, to estimate the potential risk implications of the deployment of a TravTek type system at higher levels of market penetration. Specifically, as the model traces the movement of each individual vehicle in the network on a deci-second basis, an assessment is made each second of how far the given vehicle has driven (during the past second), what type of facility it is on, whether this facility is congested, and what type of TravTek configuration (if any) is presently active in the vehicle. These measures were used to estimate a base risk and level of exposure as a function of facility type. The base risk was adjusted with a risk correction factor based on the experienced level of congestion and the particular TravTek configuration in use.

Assumption of Simulation Study

The report by VanAerde et al. presents a detailed discussion of the enhancements made to the INTEGRATION model to support the evaluation of TravTek. [3] The report also discusses at length the methods and data used to calibrate the model. The following list of modeling assumptions are extracted from VanAerde et al: [3]

- The random number seed was kept constant for all simulation runs, unless specifically noted, and thus all runs were directly comparable in terms of their outputs.
- All vehicles equipped with the TravTek system were assumed to utilize the system during their entire trip.
- All vehicles equipped with the TravTek system were assumed to comply to the route guidance system, except when they made wrong turns during their trip. (Note: data from the Yoked and OTN Studies were used to estimate the probability of wrong turns for TravTek equipped and non-equipped vehicles.)
- All guided vehicles were assumed to utilize a Turn-by-Turn display in the Nav Plus configuration with the voice guidance active.
- An ideal TravTek system was modeled as the default. In this ideal system no account was made for the fact that travel time data were broadcast as discrete travel time factors (rather than actual continuous values), and that the typical data transmission lagged for 3 to 5 min.
- Guided vehicles were assumed to have real-time travel time information on every link in the network for their entire trip.
- Background traffic was considered to follow five minimum path trees that were computed using the method of successive averages traffic assignment. These minimum path trees were updated every hour.
- Background and TravTek vehicles were assigned wrong turn probabilities per turning movement of 0.054 and 0.036, respectively.
- Link travel times were assigned a normal error for both the background and TravTek vehicles. The Coefficient of Variation (COV) of this link travel time error was varied from 5 percent to 20 percent for the background traffic and from 1 percent to 10 percent for the TravTek vehicles.

Simulation Results

Figure 35 presents results of simulation runs where the level of market penetration (LMP) and traffic demand were varied. Traffic demand was modeled at 40 percent, 80 percent and 110 percent of the p.m. peak traffic demand in Orlando.. The level of traffic demand, as expected, had an effect on the level of risk predicted for the background (non-TravTek equipped) and equipped vehicles. At higher levels of traffic demand, there is a predicted increase in risk for both background and equipped vehicles. Furthermore, there is an interaction between LMP, level of traffic demand, and the presence or absence of ATIS. For the 110 percent traffic demand condition, the model predicts greater accident risk for equipped vehicles relative to the background traffic for LMP below 30 percent due to the fact that equipped vehicles would reroute to lower class (less safe) roadways. On the other hand, for 80 percent traffic demand the risk for the equipped and background traffic are nearly equivalent at all modeled LMP.

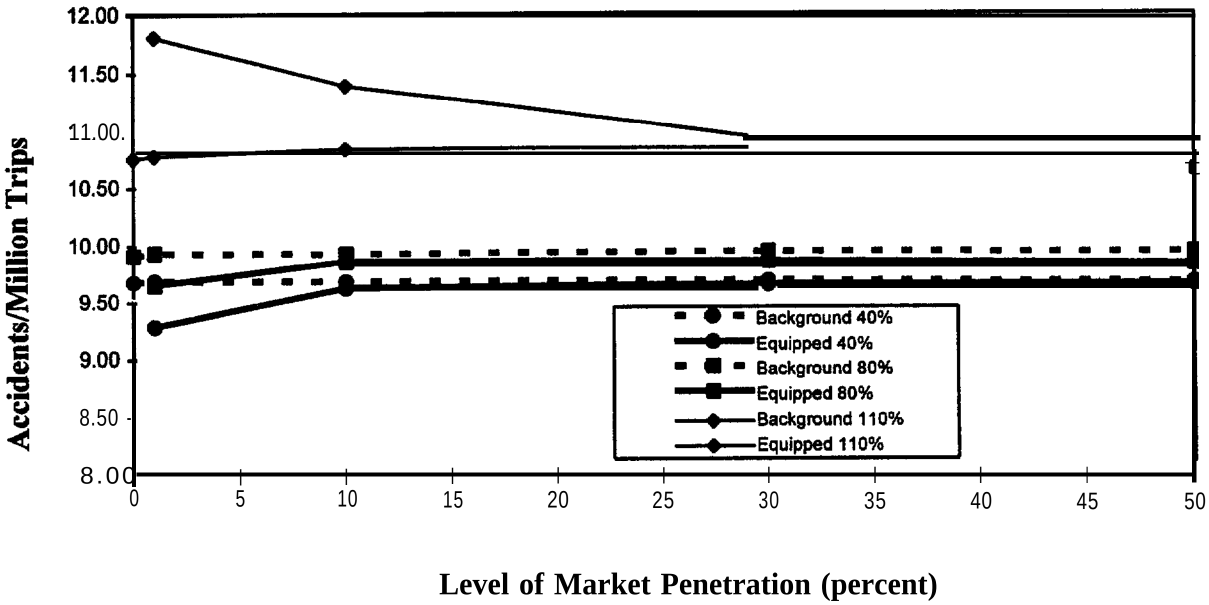


Figure 35. Orlando network level of market penetration effects on accident risk.

A more detailed analysis of the modeling study's results indicates that the overall safety neutral effect (at 30 percent or greater LMP) as a function of traffic demand condition arises out of the counterbalancing of two factors. The use of the TravTek system reduces the navigational waste associated with drivers selecting poorer routes in the absence of TravTek, and also reduces the additional travel associated with drivers making wrong turns while attempting to follow their intended routes. However, counter balancing this effect is the fact that in the study area most diversions due to congestion were from the interstate to the surface street arterials. These arterials, even when not congested, involve an accident risk that is typically higher than the interstate's risk level, even when the latter is congested.

At lower levels of market penetration we see the TravTek vehicles incurring additional risk to the benefit of the background traffic. This is due to the fact that the TravTek vehicles divert from higher to lower class facilities in response to congestion. They tend to incur risk because of these diversions. The background traffic derives a benefit because they tend to remain on the higher class roads. Also, the diversion of TravTek vehicles results in less congestion on the original route, thus decreasing the overall risk to the background traffic.

At lower levels of traffic demand (i.e., 40 percent and 80 percent) there will be less congestion on the network, resulting in fewer diversions by equipped vehicles. Under levels of lower traffic demand we see that the level of risk is lower for the equipped vehicles relative to the background traffic under LMP's less than 10 percent. For LMPs greater than 10 percent, the level of risk for the equipped vehicles (at 40 and 80 percent levels of traffic demand) is nearly equivalent to that predicted for the background traffic. INTEGRATION models the lower probability of ,wrong turns observed for the TravTek conditions in the operational study. Therefore, under conditions where there are few diversions due to congestion, the equipped vehicles will tend to remain on higher class roads and make fewer wrong turns (relative to background traffic), thus experiencing lower risk relative to the background traffic.

The results of the modeling study suggest that under congested conditions equipped vehicles will incur more risk relative to non-equipped vehicles at lower LMP. However, it is anticipated that in many other urban areas the impact of the TravTek system would potentially be more positive. The basis for this expectation is that in many other urban areas there is greater potential for either arterial to arterial diversion, or freeway to freeway diversion. In these situations the benefits of congestion avoidance would not be offset by a drop in road class and likely be sufficient in size to offset any increases in travel distance.

SUMMARY

The TravTek evaluation showed that an ATIS can be employed under normal operating conditions without degrading safety. Development of the TravTek driver interface included human factors research and analysis. [16,17] This work paid off in the fielding of a system that was easy to use, required minimal training, and was safe. [22] Human factors principles with respect to the reduction of driver attentional demand were applied in the design of the TravTek driver interface, and were verified with on-road testing (Camera Car Study). Developers of new ATIS systems need to attend to the design on the driver interface with as much emphasis as paid to the development of data bases, routing algorithms, and other system components.

The modeling results predicted that a TravTek-like system, under conditions similar to those found in Orlando, would present an increase in risk to ATIS users under conditions of high traffic demand and low LMP. At higher levels of market penetration (30 percent) or under uncongested condition, the model predicts a TravTek-like system to result in neutral to slightly positive safety impacts. The methodology presented in this paper may be applicable to other safety evaluations of ATIS. Additional human performance and safety data need to be collected to make the safety component of the INTEGRATION model more robust. The data fusion process and modeling approach presented here represent an initial step in the development of a methodology for evaluating the complex relationship among variables that can impact the overall safety of an ATIS.

CONCLUSIONS

The results showed that the TravTek system did not degrade driving safety during the one year operational test. Answers to all of the safety-related questionnaire items showed that drivers perceived that the TravTek system, either Nav Plus or Nav, as between 0.2 and 1.6 points higher (on a 6-point scale) than the Service condition. This statistically significant difference in perception of safety was supported by a 19 percent reduction in the number of observer reported close calls (OTNS and Yoked studies). Furthermore, the Turn-by-Turn display was shown to lead to safest driving performance relative to the Route Map display. The Turn-by-Turn display presented the information required for route following in a simplified manner, thus facilitating the extraction of information by drivers. Also, the Voice guidance display was shown to have a safety enhancement effect, This was especially true for the Route Map display when it was being used for route guidance.

The data fusion process complemented the independent analysis of driver performance measures, subjective responses, observer data, incidents, and accidents. Furthermore, it allowed the use of driver behavior data in the INTEGRATION model.

The modeling study showed that with 30 percent or more LMP, the TravTek system was safety neutral relative to the background traffic under congested conditions. Under uncongested conditions, the model predicted safety neutral to safety positive effects for the TravTek system. The modeling study showed how the route guidance and congestion avoidance capabilities of the system interact to affect risk. The nature of the traffic network used to evaluate the TravTek system had a significant impact on the findings with respect to risk. It is anticipated that in many other urban areas that present the opportunity for arterial to arterial diversion, or freeway to freeway diversion, the ‘Impact of the TravTek system would potentially be more positive. Finally, the modeling study predicted significant benefits for users of a TravTek-like system for factors such as time savings, reduction in the number of wrong turns (decrease in navigation errors), decrease in fuel usage, and decrease in pollution emissions.(3)

APPENDIX A. DESCRIPTION OF TRAVTEK INCIDENTS & ACCIDENTS

Incident # 1

Date: July 14, 1992 IDNO: 27371 STATUS: RENTER
Time: 12:30 p.m.
Damage: Right Door, molding broken, window broken
Vehicle Mode: Navigation Plus

Description (AVIS Accident Report)

Customer told Merible that he had an accident. Customer did not report it to me.

TISC Log Information

- Driver informed TISC of accident
- Police officer did not cite TravTek driver or driver of other vehicle

Vehicle location: Heading E
Aloma Avenue (in front of Angel's Restaurant 3084 Aloma Ave
Winter Park)

Comments

- No details of accident available
- No injuries reported
- No mention of TravTek in any of the available reports

Incident/Accident #2

Date: June 2, 1992 IDNO: 21371 STATUS: VIP
Time: 2:46 p.m.
Damage: Front of vehicle (Avis report is not specific). See comments under TISC report
Vehicle Mode: Navigation Plus

Description (AVIS Accident Report)

After making left turn I was looking at the TravTek computer screen glanced up and saw a car stop - Applied brakes and hit the rear end of the car. That was pushed into the car in front of it. Damage to car A&B no damage to car C. No injuries reported.

NOTE: **(Analyst notes)** Cars A, B, and C refer to the three cars in front of the TravTek vehicle during the collision. The car that was struck by the TravTek vehicle (A) and the car in front of the struck vehicle (B) were damaged.

TISC Log. Information

Driver was talking to the TISC on cellular phone at the time of the accident. The driver was requesting instructions for ZOOM in on the screen.

NOTE **(Analyst notes)** Based on available information, it appears that the TravTek driver was requesting for instructions for Zooming in of the route map display while the vehicle was in motion**. This function is not available while the car is in drive.**

- Police officer cited TravTek driver with careless driving
- TISC report indicates that the police estimated damage at $5,000

Vehicle location Corner of State Route 50 and State Route 436

Comments

- No injuries reported
- TravTek driver mentions use of TravTek functions before accident
- TISC report suggest that driver was attempting to use a zero-speed function (zoom on route map) while the vehicle was in motion. Also, the driver was using the cellular phone during the time of the accident.
- TravTek driver cited with careless driving by police
- This driver was a VIP from a road mapping company

Incident/Accident #3

Date: June 13, 1992 IDNO: 26631 STATUS: RENTER
Time: 9:55 p.m.
Damage: Driver side rear fender (light)
Vehicle Mode: Navigation

Description (AVIS Accident Report)

I was following directions of person employed to direct traffic out of Sea World when the bus backed into the side of our rental car. We (myself and the employee of Sea World) tried to get the bus to stop but we were not successful.

TISC Log Information

- Driver did not inform TISC of accident
- NOTE (Analyst Note) The Mid Rental Interview Report presents the following response to Item # 3 (Overall, how would you describe your experience with the TravTek system): "We have not been able to use the phone as of today (date added 6/14/92). I have not gotten past putting in the four digit code. Other than that the vehicle has been very helpful." This indicates that the car phone was not usable by the driver on the date of the accident.
- Police officer did not cite TravTek driver or driver of other vehicle

Vehicle location: Sea World Parking lot

Comments

- No injuries reported
- No mention of TravTek in any of the available reports
- Accident occurred on private property with very minor damage to the vehicles

Incident/Accident #4

Date: June 21, 1992 IDNO: N/A STATUS: SAIC
Time: no time provided
Damage: GPS satellite antenna broken
Vehicle Mode: ?

Description (AVIS Accident Report)

Vehicle was parked in above address **(address added to description by analyst: 2086** Kimberwicke Cr. Oviedo, FL) at the time of vandalism, no other damage to any part of the vehicle occurred.

TISC Log Information
None Available

Vehicle location(AVIS Report): Parked at 2086 Kimberwicke Cr., Oviedo, FL,

Comments

- Vehicle was signed out to member of TravTek Evaluation Team at time of vandalism
- Vandalism of noticeable TravTek GPS antenna

Incident/Accident #5

Date: August 3, 1992 IDNO: N / A STATUS: SAIC
Time: 2: 10 p.m.
Damage: Dent in front fender (driver side) $600
Vehicle Mode: ?

<u>Description (AVIS Accident Report)</u>

Ms. X (TravTek vehicle driver) was driving south on Palm Valley Rd., and Ms Y (other driver) was backing out of a drive-way on the east side of the street. Ms. Y did not observe oncoming traffic.

<u>TISC Lop Information</u>

- None Available
- Police officer cited driver of other vehicle for "not looking when backing up". This was provided on the AVIS accident report form.

<u>Vehicle location (from AVIS Report)</u>: Palm Valley Rd near intersection of Rouse Rd.

<u>Comments</u>

- No injuries reported
- No mention of TravTek in any of the available reports
- Operator of other vehicle cited by police
- At time of accident vehicle operated by Evaluation Team member

Incident/Accident #6

Date: August 14, 1992 IDNO: N/A STATUS: AVIS
Time: 9:00 a.m.
Damage: Door damage - Driver side
Vehicle Mode: Navigation Plus

Description (AVIS Accident Report)

Came out of car wash and slid into Toronado. Causing the accident.

TISC Log Information

- None

Vehicle location (AVIS report): AVIS Q.T.A

Comments

- No injuries reported
- The TravTek vehicle was struck by a car exiting car wash at the AVIS Q.T.A. The vehicles were being operated by AVIS employees.

Incident/Accident #7

Date: August 16, 1992 IDNO: 95181 STATUS: RENTER
Time: None provided
Damage: Right front bumper
Vehicle Mode: Navigation Plus

Description (AVIS Accident Report)

Unreported damage

TISC LOB Information : **None**

Comments

- No details of accident available
- This was unreported minor damage

Incident/Accident #8

Date: September 1, 1992 IDNO: ? STATUS: RENTER (probably walk in)

Time: None Reported
Damage: Driver side door
Vehicle Mode: ?

Description (AVIS Accident Report)

Damage to driver's door, car looked as if driven off road. Dint all underneath car also heavy on car itself. Also looked as if driven through car wash. Blue bristles in head lights.

TISC Log: Information: **None**

Comments

- No details of accident available
- Unreported minor damage to vehicle.

Incident/Accident #9

Date: September 14,1992 IDNO: N/A STATUS: AAA
Time: 4:40 p.m.
Damage: Front and right side of vehicle
Vehicle Mode: ?

Description (AVIS Accident Report)

Made full stop at stop sign. Then proceeded through intersection and did not see car approaching from right. Approaching vehicle hit the Toronado.

TISC Log: Information

- **None**
- Police officer cited TravTek driver for failure to yield right of way (from AVIS report)

Vehicle location (AVIS report): Intersection of Livingston and Altaloma, Orlando, FL

Comments

- No injuries reported
- No mention of TravTek in any of the available reports
- Vehicle was being operated by member of the Evaluation Team (AAA) during time of accident

Incident/Accident #10

Date: September 17, 1992 IDNO: 31841 STATUS: RENTER
Time: None Provided
Damage: Top of trunk and rear and right rear
Vehicle Mode: Navigation Plus

Description (AVIS Accident Report)

No accident report filed

TISC Log: Information

No mention of vehicle damage in TISC interaction reports

Vehicle location: Not Known

Comments

- No details of accident available
- Unreported damage to vehicle.
- The AVIS report does not describe the type of damage, it only shows the location of the damage on the vehicle drawing. Note: Damage on the top of the trunk may have been hail damage from the storm that occurred prior to the start of the test. However, there is no information available to determine how, when, or where the damage occurred.

Incident/Accident # 11

Date: January 11, 1993 IDNO: N/A STATUS: SAIC
Time: 9:30 a.m.
Damage: Passenger door
Vehicle Mode: ?

Description (AVIS Accident Report)

At approximately 9:30 a.m. on l/ll/93 I had just paid a $0.75 toll on the E-W exp. I was pulling out of the going west and was about to change lanes, moving to my right, I checked the rear view mirror and looked to my right, I saw no cars. As soon as I moved to my right I felt contact with another car.

TISC Log: Information

- None
- Police officer cited TravTek driver for improper change of lane

Vehicle location (AVIS & Police Report): Heading west on East-West toll road. (H900 block East-West, west bound)

Comments

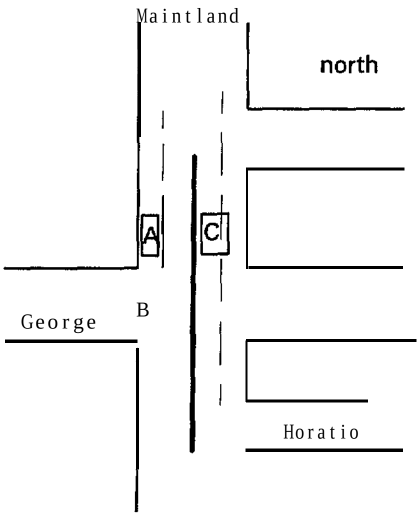
- No injuries reported
- No mention of TravTek in any of the available reports
- Vehicle was being driven by an Evaluation Team (SAIC) member at the time of the accident.

Incident/Accident #12

Date: February 13,1993 IDNO: N/A STATUS: SAIC
Time: 5:44 p.m.
Damage: Right front (no other details)
Vehicle Mode: Navigation (from TISC simulator mode)

Description (AVIS Accident Report)

Car A south bound, outside lane. Truck C stopped in line of traffic waiting to turn left on Horatio, however had left space for Maintland N/B traffic to turn left on George. Car N/B on Maintland Ave turned left unto George in front of car A. Truck C blocked view - only 1 to 2 car links to stop car A.



TISC Log. Information

- None
- Police officer cited driver of other vehicle for failure to yield

Vehicle location (AVIS Report): S/B Maintland Avenue & George Ave, Maintlan, FL

Comments

- No injuries reported
- Note: A note attached to accident report states that the TravTek driver was not using the system. Was ignoring at time because it was suggesting he turn left on Horatio and he doesn't like turning on Horatio. He was going to wait for Off-Route message so that he could press OK new route. Was not looking at TravTek screen or operating buttons at time of accident. "I was ignoring the system."
- The vehicle was being operated by Evaluation Team member at the time of accident.

Incident/Accident #13

Date: March 12, 1993 IDNO: N/A STATUS: AAA
Time: 8:45 p.m.
Damage: Driver door dents (light)
Vehicle Mode: ?

Description (AVIS Accident Report)

TravTek heading north through ???? parking lot. Other vehicle ????????? parking spot and into TravTek car. Police officer told her it was her fault but did not issue a ticket.

TISC Log Information

- None
- Police officer did not cite TravTek driver or driver of other vehicle

Vehicle location (Driver Report): 5660 Curry Ford Rd.

Comments

- No injuries reported
- No mention of TravTek in any of the available reports
- TravTek vehicle being operated by Evaluation Team member (AAA) at time of accident

Incident/Accident #14

Date: March 14, 1993 IDNO: 41351 STATUS: RENTER
Time: 10:30 a.m.
Damage: Rear light ($300 to $400)
Vehicle Mode: Navigation

Description (AVIS Accident Report)

I was rear ended while stopped in line approaching the parking gates at Universal Studios

TISC Log Information

- Driver informed TISC of accident
- Police at scene of accident; however, no police report filed because damage estimated at less than $500

Vehicle location: Heading NE
Universal Blvd., Universal Studios, FL

Comments

- No injuries reported
- No mention of TravTek in any of the available reports
- Vehicle was rear ended while stopped in line of traffic entering Universal Studios. System probably not in route guidance mode since destination would have been reached.

APPENDIX B. DATA FUSION METHODOLOGY

MAPPING OF RAW RISK SCORES ONTO A COMMON SAFETY METRIC

The first step, in deriving Integrated Risk Factors from all of the above data, was to convert the above Raw Risk Scores into compatible Normalized Risk Scores. This normalized score would essentially facilitate the translation of apples and oranges into generic fruits. In order to deal with the rather subjective nature of this exercise, a panel of subject matter experts was polled based on a series of hypothetical questions. The responses to these hypothetical questions were then translated into coefficients of a translation function, which converted the observed raw risk score into one which describes a proportional increase/decrease in accident risk, as shown below.

Questionnaire to Subject Matter Expert Panel

In order to describe the process involved in utilizing the panel of subject matter experts, it is best that an example is utilized. Panelists were told that the number of lane deviations potentially varied from 10 to 40, and that a hypothetical base reference case condition A involved 25 lane deviations. The panelist were then asked to consider how much safer a hypothetical condition B would be expected to be, given that it involved only 10 lane deviations, or how much less safe a hypothetical condition C which involved 40 lane deviations would be. The responses for the 10 lane deviations ranged from subject matter experts indicating that condition B involved from 0.5 to 0.9 times the basic risk associated with condition A, where the average and standard deviation of their replies was 0.742 and 0.163, respectively. Similarly, condition C was rated as involving from 1.10 to 1.80 times the base risk, with an average rating of 1.375 and a standard deviation of 0.256.

Development of Translation Function

The results of the above sample question, about the relative risk associated with 10 to 40 lane deviations, are illustrated in figure 36. If one considers the base response; and the average response at the better and worse than average conditions, one possesses a total of 3 points. This allows a quadratic function to be fitted, as shown in figure 37 by the solid line. This quadratic relationship, which is shown as equation 1, in turns allows the change in accident risk to be inferred for any actual lane deviation count, which may be different than any of the hypothetical counts which were rated by the Subject Matter Expert Panel.

$$TRC = a + b \times RRS + c \times RRS^2 \qquad (3)$$

Application of Translation and Normalization Functions

The application of the translation function in figure 36 is illustrated in tables 38 and 39 for a subset of sample data. It can be noted that in the first stage of the analysis, the raw number of lane deviations is translated into a transformed accident risk. Subsequently, in stage 2, this transformed accident risk is normalized with respect to the transformed accident risk for the base case, which becomes 1.0.

Table 38. Sample calculation of transformation and normalization of raw risk scores.

a. Transformation of Raw Risk Scores to Transformed Risk Scores	0.790 = a + b * RRS + c * RRS ^2.0 = 0.6343 + 0.0081 * 13 + 0.0003* 13 ^ 2.0
b. Normalization of Transformed Risk Scores to Normalized Risk Scores	0.754 = TRS(Turn-by-Turn) / TRS(Paper Map) = 0.790 / 1.048

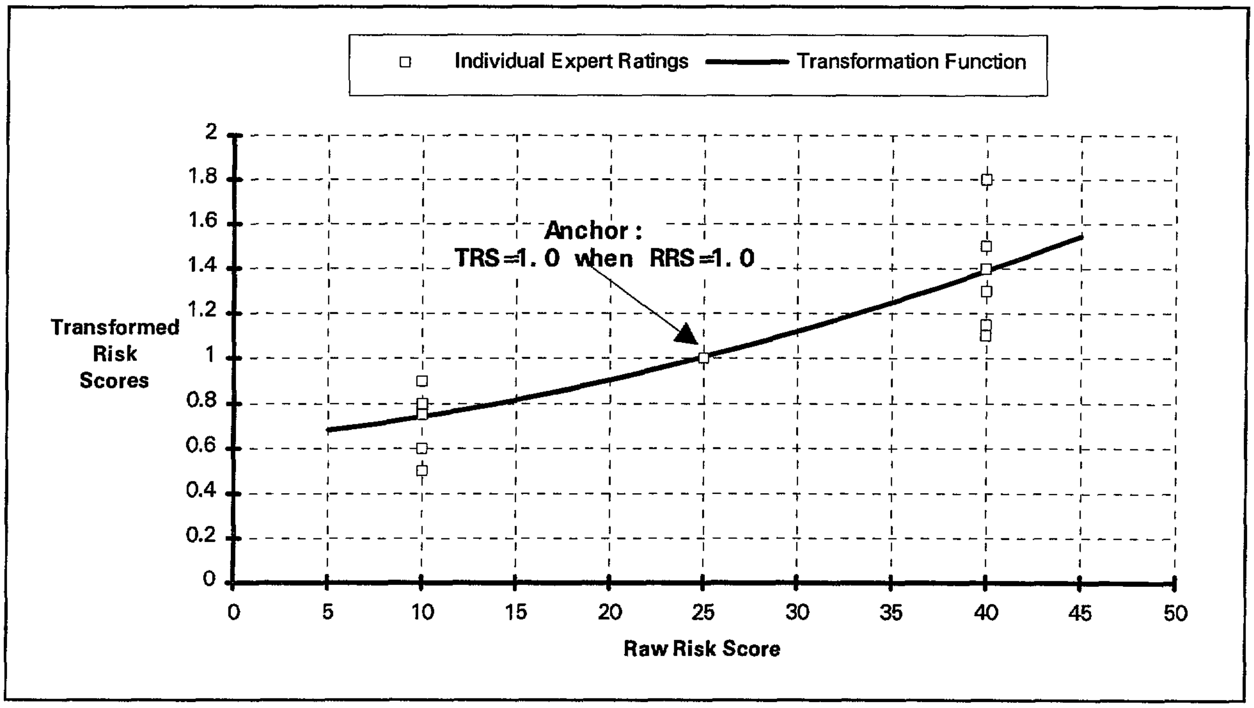


Figure 36. Illustration of calibration of transformation function for lane deviations.

Specifically, it can be noted that while the number of lane deviations varied from 13 to 34, or almost by a factor of 3.0, the Expert Panel's collective scoring only indicated that the safest to least safe configuration only varied in accident propensity from 0.790 to 1.257 or a factor of about 1.6. Subsequently, it can be noted that when the number of lane deviations for the Paper Map condition was set to 1.0, that the Turn-by-Turn without Voice and the Route Map with Voice represented about 0.786 of the Paper Map risk, while the Route Map without Voice represented 1.189 times the base risk.

Table 39. Sample results of transformation and normalization of raw risk scores.

		Raw Risk Scores				Transformed Risk Scores				Normalized Risk Scores		
		Lane Dev.	Long. Acc.	Eye Glance		Lane Dev.	Long. Acc.	Eye Glance		Lane Dev.	Long. Acc.	Eye Glance
Turn-by-Turn	Voice	13	17	17		0.790	0.943	0.700		0.754	0.813	1.030
	No Voice	15	17	59		0.823	0.943	0.873		0.786	0.813	1.283
Route Map	Voice	15	18	48		0.823	0.965	0.827		0.786	0.832	1.217
	No Voice	34	20	114		1.257	1.014	1.096		1.189	0.874	1.615
Paper Map	-	26	25	12		1.048	1.180	0.880		1.000	1.000	1.000

FUSION OF NORMALIZED RISK FACTORS

The second step, in combining the diverse data, involved the fusion of the Normalized Risk Scores, which were derived as per above for each study, into a single index across all studies. Rather than perform a simple average of the various indexes, the subject matter expert panel was consulted for a second time to weight the inputs from the various experiments, as will be discussed next.

Computation of Fusion Weights

The panel were provided with a list of factors or variables which could be utilized to derive an overall safety index, and were requested to suggest their recommended values of these weights. Table 40 provides the range of weights that were suggested for 2 sample questions, and the resulting mean and standard deviation of these weights.

Table 40. Calibration of weighting function parameters.

	Expert Number:	1	2	3	4	5	6	7	avg	max	min	Std. dev.
N/N+/ S	Crash Data	5	10	40	15	10	5	13.3	14.0	40	5	12.1
	Close calls (camera car)	30	20	20	40	30	15	20.0	25.0	40	15	8.7
	Subjective Questionnaire	10	25	30	10	10	60	6.66	21.7	60	6.7	19.1
	Close calls (Yoked study)	40	15	5	10	25	10	33.3	19.8	40	5	13.2
	Abrupt stops (Yoked study)	15	30	5	25	25	10	26.6	19.5	30	5	9.5
	SUM:	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0			
TbT / RM / Voice	Crash Data	5	5	40	10	20	10	20.0	15.7	40	5	12.4
	Risk Assessment	6	0	6	15	12	6	7.5	7.5	15	0	4.8
	Close calls	42	10	9	8	9	20	7.5	15.1	42	7.5	12.6
	Safety-Related Errors	12	10	15	7	9	14	15.0	11.7	15	7	3.1
	Lane deviations	2	16	5	20	12	15	12.0	11.7	20	2	6.3
	Longitudinal acceleration	6	4	3	12	9	7.5	6.0	6.8	12	3	3.1
	Eye glance	12	20	2	8	9	7.5	12.0	10.1	20	2	5.5
	Work load	15	35	20	20	20	20	20.0	21.4	35	15	6.3
	SUM:	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0			

Data Fusion

In order to combine the diverse sources of safety data, equation 2 was employed to establish a weighted geometric or multiplicative average. The results of this type of weighting are illustrated in table 41 for a subset of the data. It can be noted that the use of negative exponent weights permitted the inclusion of some indices where a higher value implied safer behavior into a pool where most other indices implied a less safe behavior for a higher index.

$$CRF = \prod \left(NRS_i^{w_{NRS_i}} \right) \tag{4}$$

where: $\sum \left(w_{NRS_i} \right) = 1.0$

Table 41. Sample calculations of data fusion of different data sources.

		Lane deviation N display (Camera)	Longitudinal acceleration (Camera)	Eye glance > 2.5 s (Camera)	Combined Component Risk Factor
	WEIGHTS	0.41	0.24	0.35	
Turn-by-Turn	Voice	0.754	0.813	1.030	0.857
	No voice	0.786	0.813	1.283	0.942
Route Map	Voice	0.786	0.832	1.217	0.929
	No voice	1.199	0.874	1.615	1.236
Paper Map		1.000	1.000	1.000	1.000

RESULTS OF DATA FUSION

A subset of the results of the final data fusion are illustrated in table 42, which presents the accumulation of the net component risk factors that arose from the above analysis. These Integrated Risk Factors were subsequently pooled to yield table 43, which is summarized further in tables 44, 45, and 46, as discussed next.

Table 42. Illustration of derivation of final integrated risk factor effects.

							N/N+/S	TT/RM/PM	1st	Local	35-45	Day	
							0.5	0.5	1	1	1	1	COMP
N+	TT	Voice	1st	Local	35-45	Day	0.884	0.976	1.021	1.110	0.920	1.232	1.194
						Night	0.884	0.976	1.021	1.110	0.920	0.812	0.786
					>65	Day	0.884	0.976	1.021	1.110	1.087	1.232	1.411
						Night	0.884	0.976	1.021	1.110	1.087	0.812	0.929
				Visitor	35-45	Day	0.884	0.976	1.021	0.901	0.920	1.232	0.969
						Night	0.884	0.976	1.021	0.901	0.920	0.812	0.638
					>65	Day	0.884	0.976	1.021	0.901	1.087	1.232	1.146
						Night	0.884	0.976	1.021	0.901	1.087	0.812	0.755
			2nd	Local	35-45	Day	0.884	0.976	0.979	1.110	0.920	1.232	1.144
						Night	0.884	0.976	0.979	1.110	0.920	0.812	0.753
					>65	Day	0.884	0.976	0.979	1.110	1.087	1.232	1.353
						Night	0.884	0.976	0.979	1.110	1.087	0.812	0.891
				Visitor	35-45	Day	0.884	0.976	0.979	0.901	0.920	1.232	0.929
						Night	0.884	0.976	0.979	0.901	0.920	0.812	0.612
					>65	Day	0.884	0.976	0.979	0.901	1.087	1.232	1.098
						Night	0.884	0.976	0.979	0.901	1.087	0.812	0.723
		No Voice	1st	Local	35-45	Day	0.884	0.914	1.035	1.111	0.918	0.932	0.885
						Night	0.884	0.914	1.035	1.111	0.918	1.073	1.019
					>65	Day	0.884	0.914	1.035	1.111	1.089	0.932	1.050
						Night	0.884	0.914	1.035	1.111	1.089	1.073	1.209
				Visitor	35-45	Day	0.884	0.914	1.035	0.900	0.918	0.932	0.716
						Night	0.884	0.914	1.035	0.900	0.918	1.073	0.825
					>65	Day	0.884	0.914	1.035	0.900	1.089	0.932	0.850
						Night	0.884	0.914	1.035	0.900	1.089	1.073	0.979
			2nd	Local	35-45	Day	0.884	0.914	0.966	1.111	0.918	0.932	0.826
						Night	0.884	0.914	0.966	1.111	0.918	1.073	0.951
					>65	Day	0.884	0.914	0.966	1.111	1.089	0.932	0.980
						Night	0.884	0.914	0.966	1.111	1.089	1.073	1.128
				Visitor	35-45	Day	0.884	0.914	0.966	0.900	0.918	0.932	0.668
						Night	0.884	0.914	0.966	0.900	0.918	1.073	0.770
					>65	Day	0.884	0.914	0.966	0.900	1.089	0.932	0.793
						Night	0.884	0.914	0.966	0.900	1.089	1.073	0.913
	RM	Voice	1st	Local	35-45	Day	0.884	0.996	1.068	1.116	0.917	1.070	1.098
						Night	0.884	0.996	1.068	1.116	0.917	0.934	0.958
					>65	Day	0.884	0.996	1.068	1.116	1.091	1.070	1.307
						Night	0.884	0.996	1.068	1.116	1.091	0.934	1.141
				Visitor	35-45	Day	0.884	0.996	1.068	0.896	0.917	1.070	0.881
						Night	0.884	0.996	1.068	0.896	0.917	0.934	0.769
					>65	Day	0.884	0.996	1.068	0.896	1.091	1.070	1.049
						Night	0.884	0.996	1.068	0.896	1.091	0.934	0.916
			2nd	Local	35-45	Day	0.884	0.996	0.936	1.116	0.917	1.070	0.962
						Night	0.884	0.996	0.936	1.116	0.917	0.934	0.840
					>65	Day	0.884	0.996	0.936	1.116	1.091	1.070	1.145
						Night	0.884	0.996	0.936	1.116	1.091	0.934	1.000
				Visitor	35-45	Day	0.884	0.996	0.936	0.896	0.917	1.070	0.772
						Night	0.884	0.996	0.936	0.896	0.917	0.934	0.674
					>65	Day	0.884	0.996	0.936	0.896	1.091	1.070	0.919
						Night	0.884	0.996	0.936	0.896	1.091	0.934	0.802

Table 43. Summary of final integrated risk factors for TravTek vs. non-TravTek vehicles

				N+				N				S
				TT		RM		TT		RM		
				Voice	NoVoice	Voice	NoVoice	Voice	NoVoice	Voice	NoVoice	
1st	Local	35-45	Day	1.194	.885	1.098	1.043	1.214	.899	1.116	1.061	1.012
			Night	.786	1.019	.958	1.044	.799	1.036	.974	1.061	1.018
		>65	Day	1.411	1.050	1.307	1.249	1.435	1.067	1.329	1.270	1.219
			Night	.929	1.209	1.141	1.250	.945	1.229	1.160	1.271	1.226
	Visitor	35-45	Day	.969	.716	.881	.877	.985	.728	.896	.891	.853
			Night	.638	.825	.769	.877	.649	.839	.782	.892	.857
		>65	Day	1.146	.850	1.049	1.050	1.165	.864	1.066	1.067	1.027
			Night	.755	.979	.916	1.051	.767	.995	.931	1.068	1.033
2nd	Local	35-45	Day	1.144	.826	.962	.920	1.163	.839	.978	.936	.968
			Night	.753	.951	.840	.921	.766	.967	.854	.936	.974
		>65	Day	1.353	.980	1.145	1.102	1.375	.996	1.165	1.121	1.166
			Night	.891	1.128	1.0	1.103	.906	1.147	1.016	1.121	1.173
	Visitor	35-45	Day	.929	.668	.772	.773	.944	.680	.785	.786	.816
			Night	.612	.770	.674	.774	.622	.783	.685	.787	.821
		>65	Day	1.098	.793	.919	.926	1.116	.806	.934	.942	.982
			Night	.723	.913	.802	.927	.735	.929	.816	.942	.988

Table 44. Relative impact of environmental factors on TravTek Vehicle safety.

						1st		2nd	
						Local	Visitor	Local	Visitor
						.961			
						1.059	.864		
						1.006		.917	
						1.008	.904	1.010	.824
35-45	Day	.961	1.011	.878	.924	1.064	.868	.971	.792
	Night		.912		.833	.960	.784	.873	.713
>65	Day			1.044	1.098	1.265	1.032	1.155	.942
	Night				.990	1.142	.933	1.039	.848

Table 45. Relative impact of environmental factors on non-TravTek vehicle safety.

						1st Drive		2nd Drive	
						Local	Visitor	Local	Visitor
						1.008			
						1.094	.922		
						1.030		.986	
						1.119	.942	1.070	.902
35-45	Day	1.008	1.005	.915	.912	1.012	.853	.968	.816
	Night		1.011		.917	1.018	.857	.974	.821
>65	Day			1.102	1.099	1.219	1.027	1.166	.982
	Night				1.105	1.226	1.033	1.173	.988

Table 46. Relative impact of vehicle configuration factors

						Voice	NoVoice
						.961	
						.963	.959
NAV+	TT	.961	.942	.953	.934	.958	.910
	RM		.981		.973	.952	.993
NAV	TT			.969	.950	.974	.925
	RM				.989	.968	1.010

Pooling of Data Fusion Factors

The pooling of various data fusion factors was performed through a cross multiplication of the various factors that would modify the base risk. Specifically, it can be noted from the first line in table 42 that the accident risk associated with a N+ vehicle, which was operated with a Turn-by-Turn screen and with voice active, would when taken out during the day by a 35-45 year driver for his/her first drive be 1.194 times the base risk. This assessment is based on the fact that N+ vehicles represented 0.884 times the base risk, Turn-by-Turn represented 0.976 times the base risk, while Voice represented 1.021 times the base risk, etc.

It can be noted that while the N+ effect was unconditional, the impact of Turn-by-Turn was conditional on the presence or absence of the Voice factor. Similarly, the impact of a person taking a first drive was dependent on their use of a Turn-by-Turn display with or without voice. It should also be mentioned that, while the First Drive, Local, Age and Day time factors were taken at full strength (weight = 1.0), the N+ factor and the Turn-by-Turn display factors were only taken at half strength (weight = 0.5). This distinction was made to reflect the fact that the comparison of N+ vs. S and Turn-by-Turn vs. Paper Map both essentially represent the same with vs. without TravTek effect.

Final Integrated Risk Factors

Table 43 represents the overall risk Table associated with the Gadget Factor analysis. Specifically, the tabulated values represent the final results of the cross multiplication which were illustrated in table 42 for each of the 16x8 different conditional factors. In addition, the final column represents the base risk for the Services condition.

From the top left cell in table 43 it can be inferred that a N+ vehicle with a Turn-by-Turn display and its Voice active for a 35-45 year old Local driver on their first drive during the Day would result in a risk which is 1.194 times the base risk. However from the cell below it, it can be noted that the third cell from the top indicates that at Night that risk would drop to 0.786, while the adjacent cell with the Voice turned off this risk would be only 0.885. The interaction effect can be noted when it is realized that without Voice at Night the risk would have increased to a high of 1.019. Alternatively, the third cell from the top indicates that an individual who was over the age of 65 would experience, for the initial conditions, a risk which is 1.411 times the base.

Summary of Integrated Risk Factors

A convenient summary of the integrated risk factor effects can be found in table 44,45, and 46. The column totals in table 44, which represent the aggregated results for N/N+/Voice/Turn-by-Turn/Route Map combined, indicate that for a local driver the risk for a Local Driver of 1.059 reduces to 0.864 for Visitors, while the risk of 1.006 for First Drives, drops to 0.917 during the Second Drive. Similarly, the row totals indicate that the Day risk of 1 .0l 1 drops to 0.912 at Night, and that the 35-45 age group risk of 0.878 increases to 1.044 for the 65 and over group.

Table 45, which provides a similar summary for the non-TravTek vehicles indicates that the same Local to Visitor effect and Age effect are present, but that the First vs. Second Drive-and Day vs. Night effects are much less. Finally, the table 46 summary indicates that the impact of Voice vs. No Voice is overall negligible because the positive effect of Voice on the Route Map configurations is offset by the negative effect on the Turn-by-Turn configuration. In terms of row averages, the Turn-by-Turn is about 4 percent safer than the Route Map, while the difference between N and N+ is about 1.5 percent.

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HSR-10/2-96(500)EW